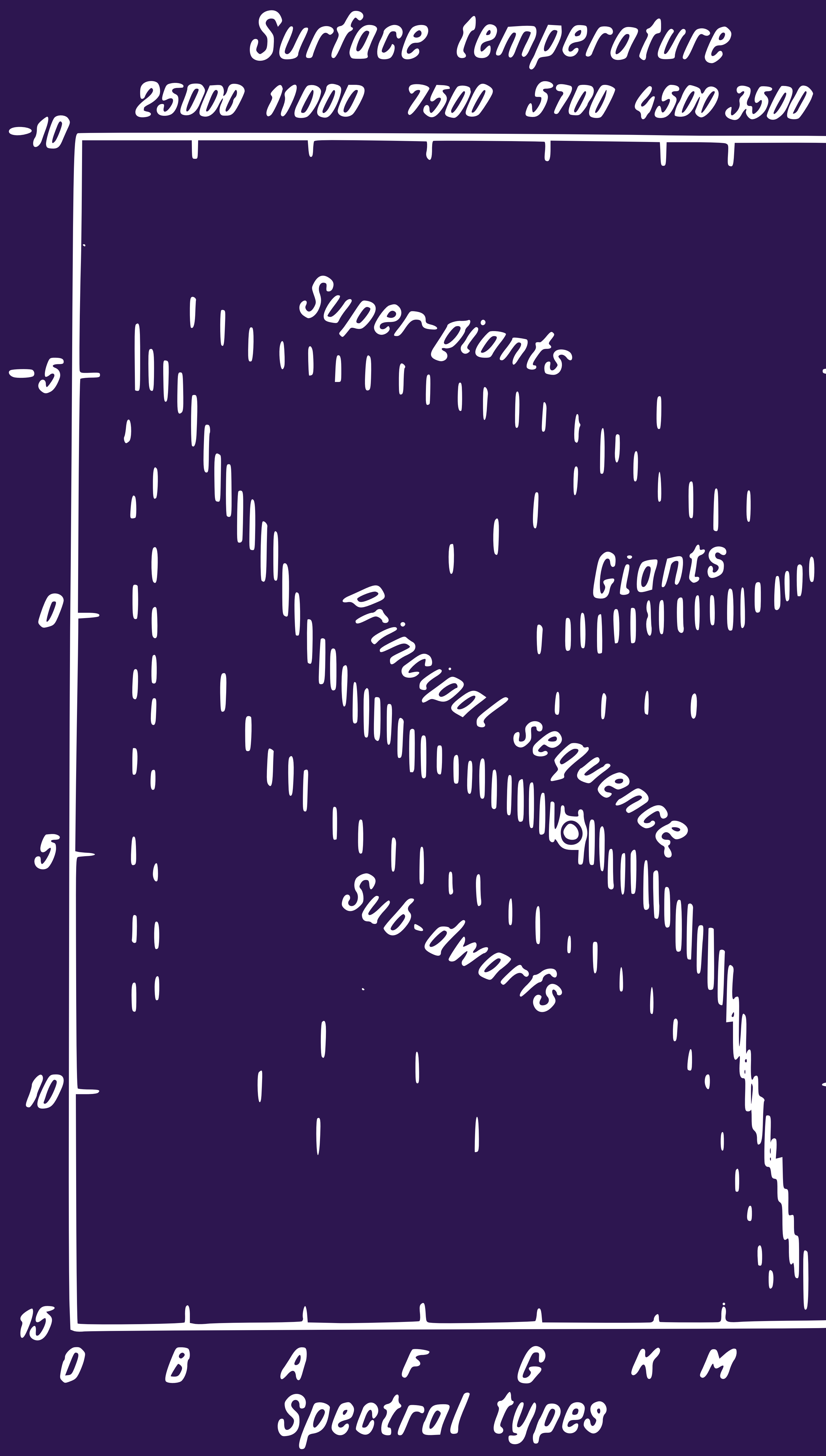
A. Oparin, V. Fesenko

THE UNIVERSE



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A. OPARIN and V. FESENKOV

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FOREWORD

Does life exist throughout the Universe and, in particular, on the planets of our solar system? In this book the authors make an attempt to answer this question on the basis of the latest information in natural science. The contents of the book were thoroughly discussed by both authors. The introduction and the concluding chapter were written by the two authors jointly. The first chapter belongs to the pen of A. Oparin, the rest—to V. Fesenkov.

INTRODUCTION

The idea that life exists everywhere in the world around us belongs to the general a priori ideas that have reigned over the minds of man since hoary antiquity. The problem of the existence of life throughout the Universe aroused sharp and heated ideological discussions between the different schools of philosophy in various epochs and at various stages of culture. These discussions, however, confined themselves mainly to explanations of the causes and philosophical interpretations of this phenomenon, while the idea itself was accepted by the overwhelming majority of people as incontestable truth.

Elements of the conception of the universal existence of life are found in the very sources of European philosophy—the Miletians in the 6th century B.C. These ancient Greek materialist philosophers regarded life as an inalienable and primary property of all matter in general. They, therefore, believed that the world had always been alive (this line in philosophy is known as hylozoism).

The so-called panspermic doctrine, formulated by Anaxagoras, was of a somewhat different nature. It maintained that invisible "ethereal germs of life," which give rise to all living creatures including man, were dispersed throughout the world.

The panspermic doctrine was further developed by the Roman philosophers and the Neo-Platonists—a philosophical school of the early centuries A.D. The doctrine was becoming increasingly idealist; it was later adopted by early Christianity and formed part of the teachings of the "fathers of the church." For example, so authoritative a theologian as Saint Augustine taught that the world was filled with hidden germs of life, the invisible, mysterious seeds (*occulta semina*) of a spiritual principle, which generated the various living creatures from earth, air and water.

For the Middle Ages, for the early and late scholastics, the Earth was the centre of the Universe, and the existence of life was, therefore, conceived only within this narrow framework circumscribed by the Ptolemaic spheres. The situation changed sharply after Copernicus announced his brilliant heliocentric system. In this system the Earth was relegated to a modest position along with the other planets revolving around the Sun. This alone, naturally, gave rise to the idea that life existed on other planets similar to the Earth.

The daring idea that there were many worlds inhabited by living creatures was first expressed by Giordano Bruno, the great 16th century thinker who drew broad inferences from the teaching of Copernicus at the time the all-powerful Catholic Church still rejected it. In his work *Del' Infinito Universo e Mondi* Bruno wrote: "There are innumerable Suns and innumerable Earths, which revolve around their Suns, as our seven planets revolve around our Sun. . . . These worlds are inhabited by living creatures."

It is but natural that at a time when the church believed the Earth to be the centre of the Universe and the stars and planets mere luminaries, intended to serve man created in the image of God, the ideas of Giordano Bruno should be regarded as a heresy.

For his propaganda of the new world outlook he was violently persecuted by the Inquisition. After long incarceration he died in an auto-da-fé in 1600.

The struggle begun by Bruno continued during the first decades of the 17th century. Galileo, who had done more than anyone else to spread the right ideas on the structure of the planetary system and the surrounding world, was condemned by the Inquisition and confined to Arcetri for the rest of his life. René Descartes, who was also distinguished for his independent thinking, preferred to emigrate to Holland where the power of the churchmen was not so palpable; but he was persecuted there, too, only because he was suspected of adhering to the heliocentric doctrine.

It should be noted, however, that the idea itself that life existed everywhere, irrespective of the heliocentric system, caused no objections on the part of the churchmen. St. Augustine's teachings that germs of life are scattered everywhere were never doubted or criticized by the Christian Church during the Middle Ages. In the middle of the 17th century Athanasius Kircher, who enjoyed a good deal of authority in Catholic circles, reaffirmed this doctrine in the panspermic theory he had developed; according to this theory the germs of life are present everywhere, in chaos as well as in every element of the Universe.

The struggle was centered around the heliocentric doctrine. But the accumulation of new facts and observations, the very harmony of Copernicus' system as compared with Ptolemy's intricate and artificial structure, and, especially, the development of physics and mechanics which eliminated all possibilities of objecting to the new world outlook, had won for this doctrine such general recognition by the end of the 17th century that the Catholic Church no longer dared openly persecute its adherents and had to reconsider its positions.

All this enabled Bernard de Fontenelle, Secretary of the French Academy of Sciences, to publish in 1686 a book *Entretiens sur la pluralité des mondes* no longer fearing persecution by the church. The book written in the form of a fascinating dialogue played a big part not only in popularizing the heliocentric system, but also in propagating the idea that life existed throughout the Universe. Soon after its appearance Fontenelle's book was translated into many European languages, including the Russian in 1740 and 1761, the last time owing to the efforts of Lomonosov.

In setting forth Copernicus' theory of planetary motion Fontenelle immediately inferred that the planets were inhabited by thinking creatures though he had no reason to do so save by an analogy with the Earth. According to his description the inhabitants of the different planets have attributes characteristic of the heavenly bodies which they inhabit. Thus, the denizens of Mercury "must be fools because of their excessive vivacity," while on Saturn the "inhabitants are so dull that it takes them a whole day to comprehend and answer a question."

Fontenelle wanted no conflicts with the Church. On the contrary, taking for granted that the Earth had lost its central position in the Universe, he believed that the most widespread existence of life in the Universe was the only idea compatible with the "omnipotence of the Creator."

The Catholic Church, which was finally compelled to suspend its interdiction on Copernicus' brilliant book, also accepted this interpretation.

The Catholic theologians of all ages have declared the possibility of the existence of inhabited worlds, besides the Earth, to be quite in keeping with the doctrines of the Church. Thus, the theologian G. Van-Nort in his treatise on God the Creator, published in 1920, writes: "Those who believe in the existence of thinking creatures on other celestial bodies, besides the Earth, in no way contradict the true faith." F.I. Connelly and other theologians have made similar statements.

The great importance, of which the victory of the heliocentric doctrine was to the further development of the idea of many inhabited worlds, can be shown on numerous examples. It is obvious, in particular, from the propaganda of the heliocentric world outlook in Russia. One of the first books setting forth Copernicus' system in Russian was the *Cosmotheoros* by C. Huygens, anonymously translated by

Y. Bryus by direct order of Peter I under the title of *Book of World Outlooks or Opinions of the Heavenly and Earthly Globes* (Petersburg, 1717). The book contains various proofs of the veracity of Copernicus' doctrine, but at the same time, after a rather strict scientific exposition, it makes a purely fantastic description of the inhabitants of the different planets.

The articles in the *Monthly Writings*, which the Academy of Sciences published since 1755 on Lomonosov's initiative to popularize science, pursued the same idea. In setting forth the heliocentric system Academician Franz Epinus in his book *Discourses on the Structure of the World* (Petersburg, 1770), also defended the idea that the planets were inhabited, but did it more scientifically.

Of particular importance to the development of the problem under discussion were the statements made by Mikhail Lomonosov, a consistent and ardent adherent of the heliocentric system and the idea that the worlds were inhabited. In his famous *Meditation* on the Aurora Borealis he wrote:

The men of wisdom do proclaim:
Myriads of worlds fly there through space;
And countless suns pour forth their flame,
And time and nations run their race.
All nature's powers in harmony
There glorify the Deity.

In the last two verses Lomonosov outlined with brilliant perspicacity the two principal trends of the subsequent development of the idea that life exists throughout the Universe. Although Lomonosov pays tribute to his time and speaks of the "glory of the deity," for him as a scientist and materialist the centre of gravity of the problem lay in the unity of the laws governing the material world. The multiplicity of inhabited worlds reflected for Lomonosov only the "forces of nature," the eternal laws of nature, which reign equally throughout the Universe. The subsequent scientific materialist investigations of the problem under discussion were pursued in this direction.

On the contrary, for idealism, which asserts the primacy of mind over matter, and, particularly, for religion, the entire meaning of the existence of other inhabited worlds has come down only to the "greater glory of the deity," to the "*ad majorem dei gloriam,*" for which the fires of Inquisition burned in their time, including the fire, which consumed Giordano Bruno.

According to these views the Universe was created by a deity with a definite purpose, which is in the existence of life even of the thinking creatures, who should cognize and glorify their creator; therefore, all celestial bodies must be inhabited by living beings, and if a planet is uninhabited it does not serve its cosmic purpose.

This idealist trend found its vivid expression in the 19th century in the works of C. Flammarion, the founder of the French Astronomical Society, convinced idealist and spiritist.

In his book *La pluralité des mondes habités*, published in 1875 and widespread in France and other countries, as well as in his other works, Flammarion develops the idea that life is the aim of planet formation. Thus, he writes as regards Jupiter: "Life is the aim of its formation just as it was the aim of the formation of the Earth."

Modern idealists are as prone to populate the cosmic bodies with living creatures as were their predecessors and make similar declarations on the "cosmic aim" and the "divine creator" (for example, Smart, British astronomer /1952/, K. Heyer, American astronomer /1954/ and P. Chêvenard, Chairman of the French Astronomical Society /1954/).

But the problem of the existence of life throughout the Universe has attracted the attention of many naturalists of the last and the current centuries, who could not and would not regard it as "divine aims," but have striven for its scientific solution. However, in the 19th century, and even in the beginning of our own, science had very little factual information concerning the physical nature of planets and the conditions required for the origination and existence of life. This gave rise to all sorts of speculative and very far-reaching inferences frequently based on very doubtful, uncritically accepted and casual observations.

As examples of this we can cite the discovery of "artificial canals" on Mars or the later assertions made by W. Pickering, well-known selenologist, that the Moon was inhabited by insects which by their mass migrations conditioned certain changes in the shape and intensity of the spots he had observed on the lunar disk.

But the scientific literature of the time contains an even greater number of speculative judgements made on the problem under discussion not only by astronomers, but also by physicists, chemists, geologists and biologists. In most of the cases these judgements reflected the metaphysical approach to living nature, which was widespread among the naturalists of the 19th century. The three main trends in the solution of this problem may be outlined in the following somewhat schematic way.

The first continues, as it were, the line of the ancient Greek hylozoists: life must exist everywhere in the world around us because it is the primary attribute of matter in general. It does not necessarily have to be represented by creatures similar to our earthly organisms. No conditions, therefore, even those on the surface of stars, should exclude the possibility of life.

Preyer's theory, for example, which was quite popular at the end of last century, is a vivid expression of this point of view. According to Preyer, it is not the living substance that originates from the lifeless, but, on the contrary, the latter is discharged by living organisms in the form of a dead mass. In the beginning, therefore, the entire fiery-liquid mass of the Earth was alive, but as it cooled the greater part of the bodies, which composed it, "died and became extinct" forming the dead, inorganic substance, while life persisted only in the form of modern protoplasm.

Running close to this "theory" are the numerous utterances (especially in popular-science literature) about some fantastic "quartz" creatures, whose body cells contain silicium instead of carbon and because of this they can live at such high temperatures as not a single form of life on the Earth can withstand.

There are, certainly, no scientific grounds for this reasoning and it does not bring us one iota closer to the solution of the problem.

The second trend, which was quite widespread in the scientific literature of the 19th and 20th centuries, revives the panspermic theory. It springs from an essentially idealist conception of the eternity of life, which rejects any possibility of origin of organisms and asserts that living creatures and their germs can only be carried over from one celestial body to another. Many outstanding naturalists of the 19th and 20th centuries, including J. Liebig, H. Helmholtz and S. Arrhenius, concurred with this trend.

According to Liebig the "atmospheres of the celestial bodies and the revolving cosmic nebulae may be regarded as eternal repositories of animated form, as eternal plantations of organic embryos," whence life is dispersed throughout the Universe in the form of these germs. Similar ideas were later expressed by Lord Kelvin in England, Van-Tieghen in France, Helmholtz in Germany, and many others.

As early as the beginning of our century the famous Swedish physico-chemist A. Arrhenius came forward with the radio-panspermic theory, which had won wide popularity at the time. In his works dealing with this problem Arrhenius described how particles of substance, tiniest granules and living spores of micro-organisms connected with them, break away from the surface of planets inhabited by living beings and are carried into cosmic space. They are carried about in cosmic space retaining full viability and flying with terrific speed from one celestial body to another owing to the pressure which the light of the Sun and other stars exert on them. Finding themselves on planets where the conditions are already fit for life the spores sprout and the organisms, originating from them, become the progenitors of the entire living population of the given celestial body.

Arrhenius' theory had many ardent adherents in the world of science. It was defended in the Soviet Union, in particular, by Academician S. Kostichev, Academician P. Lazarev, and quite recently by L. Berg. The latter voiced the idea that from the very beginning the Earth "might have inherited germs of life or a ready-formed complex of primary organisms" from the dust or meteorite matter from which it was formed.

Though Arrhenius gave a rather detailed physical explanation of the mechanism of spore transportation his theory, however, found itself at variance with the latest biological data.

We must also make mention of the fact that at the end of the last and in the beginning of the present century some naturalists began rejecting the "equal forces of nature" of which Lomonosov had written in his time. They began to regard life and its origin not as a phenomenon governed by laws, but as a fortunate occurrence which may never be repeated anywhere.

Among the astronomers this point of view was supported by Jeans, who regarded even the formation of our planet as a result of an accidental and rather unusual meeting of two stars in space. In France A. Dauvillier in his voluminous book *Origin, Nature and Evolution of Planets* (1947) regards the origin of life on the Earth as a result of a "purely accidental concatenation" of organic substances, the recurrence of which is extremely improbable. In biology a similar point of view is developed by many followers of T. Morgan. Thus, G. Meller wrote very recently that life originated in the form of a primary gene substance (immediately endowed with all the attributes of life) simply as a result of a "fortunate chemical combination."

It is clear that such assertions which substitute fortuity for natural processes lead us away from a scientific solution of the problem.

The general principles developed by dialectical materialism offer the naturalists entirely different and very extensive prospects for the scientific elaboration of the problem on hand.

From the point of view of dialectical materialism life is material in its nature, but is not an inalienable property of all matter in general. On the contrary, it is inherent only in living beings and is not found in objects of the inorganic world. Life is a special, very complex and perfect form of motion of matter. It is not separated from the rest of the world by an unbridgeable gap, but arises in the process of the development of matter, at a definite stage of this development as a new, formerly absent quality.

Already at the end of last century F. Engels characterized this quality by giving a brilliant definition of life, which far from losing its significance has been even more fully confirmed and grounded by the data of modern biology. Engels wrote: "Life is the mode of existence of protein bodies, the essential element of which consists in *continual metabolic interchange with the natural environment outside them*, and which ceases with cessation of this metabolism bringing about the decomposition of the protein."[1]

Engels, thus, defined the protein bodies as the material carrier of life and the metabolic exchange of substances as the quality which makes us regard life as a special form of motion of matter.

Matter may develop in different, very diverse ways and in the world that surrounds us there are, undoubtedly, numerous and, at times, very complex and perfect forms of motion of matter, many of which we may not as yet even suspect. But we would be totally unwarranted to call any of these forms life if they differ radically from the life represented on our planet by the sum total of the various organisms; we must, therefore, exclude from the scientific practice any and all dreams of quartz organisms and similar "fiery" beings.

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[1] F. Engels, *Dialectics of Nature*, Moscow 1954, p. 396.

Engels also levelled his crushing criticism on all the theories, which spring from the principle of the eternity of life, and showed the incompatibility of this principle with consistent materialism. Commenting on Liebig's thesis, according to which "life is just as old and just as eternal as matter itself," Engels wrote:

"Liebig's assertion that carbon compounds are just as eternal as carbon itself is doubtful, if not false.

"... The compounds of carbon are eternal in the sense, that under the same conditions of mixture, temperature, pressure, electric potential, etc., they are always reproduced. But that, for instance, only the simplest carbon compounds, CO_2 or CH_4, should be eternal in the sense that they exist at all times and more or less in all places, and not rather that they are continually produced anew and pass out of existence again—in fact, out of the elements and into the elements—has hitherto not been asserted. If living protein is eternal in the same sense as other carbon compounds, then it must not only continually be dissolved into its elements, as is well known to happen, but it must also continually be produced anew from the elements and without the collaboration of previously existing protein—and that is the exact opposite of the result at which Liebig arrives."[1]

Life is not transported like "Vesta's inextinguishable torch," from one celestial body to another in the form of ready-made germs, but originates anew each time the requisite conditions are on hand in the process of the development of matter. Consequently, the origin of life is not a "fortunate," extremely improbable event, but quite a regular phenomenon subject to a deep scientific analysis and all-round study.

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[1] F. Engels, *Dialectics of Nature*, Moscow 1954, p. 394.

It is obvious that there must be numerous inhabited planets in the Universe and, in particular, in our Galaxy. This quite indisputable assertion, however, is based on considerations of a general nature and must be confirmed in each concrete case by an examination of the actual conditions which prevail on the cosmic bodies accessible to investigation by the methods of modern science.

The task of modern natural science as regards the problem of the existence of life throughout the Universe consists, primarily, in forming a true idea of the possibility of the origin and subsequent development of life on any particular celestial body by analyzing the very incomplete factual material at the disposal of astronomy, biology and other sciences. But as much as we should like to populate any particular planet with living creatures, especially the planets where the conditions are apparently forming favourably, we must make our final conclusions only on the basis of a critical appraisal of the facts we obtain from our actual observations.

This book presents an attempt at such an analysis.

Chapter I

LIFE AND ITS ORIGIN

Only a direct study of the living organisms inhabiting a particular celestial body, or at least their fossil remains, may be considered irreproachable and strictly scientific proof of the existence of life on that planet. In the latter case we can at least judge about the past of a planet as the paleontologists do with respect to plants and animals which formerly existed on the Earth.

For most of the heavenly bodies, however, this direct study could be made only on the basis of inter-planetary travel, which at the present state of science and engineering is still but a tempting dream, though tolerably feasible.

The only unearthly objects which now lend themselves to scientific investigation as regards the existence of life on them are meteorites. If they are fragments of a formerly existing planet, as most of the astronomers believe, we cannot deny beforehand the possibility of the existence of living organisms or their remains on them. This idea has long been current in scientific literature, particularly, in connection with the panspermic theory. Many naturalists believe the meteorites to have been precisely the inter-planetary ships on which the germs of life at one time reached the Earth from other worlds.

The discovery of carbonaceous substances akin to hydrocarbons in many stone meteorites provided the main reason for these assumptions. As early as 1857, for example, Wöhler managed to extract a certain amount of an organic substance, resembling ozocerite, from a stone meteorite which had fallen near Kaba, Hungary. When analyzed, the substance was found to be a high molecular hydrocarbon. A similar substance was extracted from a meteorite which had fallen in Cold Bokkeveld, South Africa. This meteorite contained up to 0.25 per cent hydrocarbon. Melikov and Krzhizhanovsky later found a small amount of hydrocarbons in a silicate meteorite which had fallen in the village of Migei, Yelizavetgrad Uyezd, Kherson Gubernia, in 1889. The chemical analysis of the Orgueil Meteorite made by Kloez showed the presence of an amorphous substance quite similar to the humus substances of some of the mineral fuels.

At the time the presence of hydrocarbons in meteorites was first established the firm opinion still prevailed that organic substances (and, hence, hydrocarbons) could be formed under natural conditions only by living organisms. Many scientists, therefore, assumed that the hydrocarbons in meteorites were a secondary formation resulting from a decomposition of organisms which had once inhabited them.

On the strength of this it was quite natural to infer that live bacteria or their spores may be present in the meteorites.

After extensive investigations by D. Mendeleyev and other chemists it is now well known that hydrocarbons and their derivatives may easily originate under natural conditions in an inorganic manner, particularly, from cohenite, a mineral composed of the carbide of iron, nickel and cobalt, and contained in meteorites.

J. Smith has shown that the organic substances in the Orgueil and similar meteorites could have formed as a result of a reaction between carbonaceous iron and iron disulphide. From the Nogoya and Alais meteorites Smith extracted even sulphur-containing hydrocarbons of the $C_4H_{12}S_5$ type. He points out that there is no reason to associate the formation of these organic compounds with organisms.

In his time M. Berthelot and, independently of him, Schutzenberger came to a similar conclusion, by showing that the hydrocarbons found in meteorites are similar to those formed in the smelting of iron under temperatures absolutely precluding any possibility of life. Thus, the presence of carbonaceous substances can now no longer serve as proof of the existence of traces of life on these celestial bodies.

The numerous attempts directly to discover germs of microbes in meteorites also failed to yield entirely reliable results. According to C. Meunier's report, already Pasteur (whom Meunier supplied with samples of carbonaceous meteorites) tried to extract viable bacteria from them. For this purpose he designed a special probe which enabled him to take samples from the inner parts of meteorites. But Pasteur obtained negative results in all cases and, therefore, did not publish them. In their subsequent attempts scientists similarly failed to discover living beings in meteorites.

The only exception is C. Lipman's report published in 1932. The author described the investigations he had conducted on numerous stone meteorites. He had sterilized the surface of the meteorites and had taken every precaution to preclude the possible penetration of earthly bacteria; but in many cases he happened, nonetheless, to obtain colonies of bacteria in the form of bacilli or cocci by planting pulverized particles of meteorites in a nutritive medium.

This report attracted the attention of broad scientific circles and was even cited in some textbooks, but regrettably has not yet been confirmed by anyone else. The fact that Lipman obtained microbes identical with the ordinary earthly bacteria is deserving of attention. Since bacteria are so variable and so readily adapt themselves to their external environment it is difficult to suppose that the same forms of micro-organisms exist on the other celestial bodies as do on our planet. It seems much more probable that despite all his precautions Lipman was unable to prevent the penetration of earthly bacteria into the meteorites he investigated when he pulverized them. In a letter to one of the authors of this book Lipman does not insist that his data are absolutely reliable.

As a matter of fact, it would be hard to assert the existence of organisms in meteorites at the present state of science. If life had ever or in any manner developed on these meteorites or on the planets from which they were formed, it would have undoubtedly left some trace in the form of biogenic rocks. But even the most painstaking search failed to discover any traces of these rocks in meteorites. According to A. Fersman, F. Levinson-Lessing and other scientists, the meteorites contain nothing resembling sedimentary rocks or in any way connected with manifestations of biological processes.

The abiogenic mode of formation of carbonaceous compounds, found in meteorites is now confirmed by the data of isotopic analyses of meteorite carbon. We must, therefore, reject the possibility of life on meteorites and on the hypothetical planet from which they may have formed.

The establishment of the presence or absence of biogenic substances on other celestial bodies, particularly, the planets of our solar system, might serve as a rather reliable argument for or against the existence of living beings on these planets now or at least, in the past. True, our possibilities are much more limited than in the case of meteorites which are accessible not only to chemical analysis but to mineralogical examination as well. We get the data on the chemical composition of the surface and atmosphere of the planets only through a spectral analysis, but under favourable conditions even this might tell us a good deal.

Of special interest from the above point of view is the molecular oxygen which forms a considerable part of the terrestrial atmosphere. According to V. Vernadsky all this oxygen formed biogenically in the process of photosynthesis effected by green plants. V. Goldschmidt points out the fact that despite the presence of considerable quantities of free oxygen in our atmosphere only the most superficial layer of the Earth's crust is oxidized while the deeper layers belong to the clearly expressed reducers which avidly combine with oxygen. Goldschmidt illustrates this point by the well-known fact that erupted lavas have black, green and grey coloration, i.e., contain ferrous oxides. On the contrary sedimentary deposits—clay, sand, etc.—have red and yellow colours because of the ferric oxides they contain. Thus, before our very eyes the oxygen is gradually consumed by the change of the igneous rock into sedimentary and it is only the process of photosynthesis that causes the constant presence of oxygen in the Earth's atmosphere. Goldschmidt figured out that the atmospheric oxygen would disappear in a very short time (geologically speaking) if the entire flora of the Earth had suddenly perished, because it would be fully absorbed by the rocks not yet saturated with it.

A direct discovery of molecular oxygen in the atmosphere of a given planet might, therefore, serve as a basis for the assumption that organisms capable of photosynthesis, similar to the plants on our Earth, are present on this planet.

Regrettably, the observation data on Venus and Mars, the two most interesting planets in this respect, do not point to any noticeable amounts of molecular oxygen. On the other hand, the absence of molecular oxygen can in no way serve as proof of the absence of life, because we know numerous anaerobic organisms which do not need this gas for their life's processes. Thus, the discovery of oxygen in the atmosphere of the planets mentioned does not give us any facts proving the existence or absence of life there.

Molecular nitrogen, another gas of the terrestrial atmosphere, which, as V. Vernadsky pointed out, also originated as a result of the activity of organisms—denitrifiers, may, undoubtedly, also have been of an abiogenic origin. It originates in the inorganic oxidation of ammonia taking place under constant dehydrogenation which must have occurred at a certain period of the existence of the Earth and terrestrial planets. The discovery of nitrogen in the atmosphere of planets is, therefore, less significant than the discovery of oxygen.

This pertains in even greater degree to carbon dioxide which in the process of formation and development of planets could have easily originated in their atmospheres abiogenically as is partly the case in the Earth's atmosphere today.

The organic substances, in particular, the hydrocarbons and their closest oxygen and nitrogen derivatives can primarily also originate, as has been pointed out, on the most extensive scale abiogenically, and their origin must not necessarily be connected with the appearance of living beings. The discovery of methane in the atmosphere of Jupiter and Saturn can, therefore, in no way serve as an argument in favour of the existence of life on these planets.

To be sure, the discovery on the planets (at least spectroscopically) of such organic compounds as porphyrine or nucleotides, so typical of organisms, might serve as an argument in favour of the existence of life, but modern methods of research are not efficient enough as yet.

In particular, the attempts to discover chlorophyll on the surface of Mars have failed, but that does not warrant the final conclusion that there is no life on Mars, since according to G. Tikhov's investigations many representatives of the Earth's flora definitely containing chlorophyll do not show corresponding absorption when subjected to a spectrophotometric analysis.

Nor do the other data obtained in spectral analyses of planets, in photographing the planets with the use of different light filtres, in studying the degree of polarization, reflecting power, heat regime, etc., give us indubitable proof of the existence or absence of life on the Venus or Mars, so close and in many respects so similar to the Earth, because they usually characterize the summary physical properties over extensive regions of a planet's surface.

Hence, we do not as yet have sufficiently reliable methods to enable us directly to discover any signs of life even on the nearest celestial bodies—the planets of the solar system. It goes without saying that this conclusion pertains in an even greater measure to the planets revolving about the other stars of our Galaxy, where, theoretically speaking, life should have originated at some time or other.

For our judgements we are, therefore, forced to use the indirect method which consists in the study of the chemical and physical conditions obtaining on the surface of the planets and in comparing them with the conditions necessary for life. Of course, by this indirect method we can only establish a degree of probability of the existence of life on any given celestial body.

The final decision must, undoubtedly, be made only on the basis of direct observation. But the method mentioned can give us at least an idea where we are justified in looking for life and where these endeavours are absolutely hopeless.

Most of the modern investigators interested in the problem of life in the Universe most frequently use this method. But we encounter much greater difficulties than is usually supposed even in this method. A simple statistical study of conditions and their mechanical collation may in a number of cases lead to wrong inferences. In the first place, we must not forget that the physical and chemical conditions on the surface of the planets have changed in the process of their origin and development. Secondly (and this is particularly important), life in its origin and subsequent development went through a number of stages at which entirely different physical and chemical conditions may have been required. The very origin of certain forms of life is the result of definite external influences, the expression of the remarkable unity of the organism and its invironment so vigorously stressed by the Michurin teaching.

But it is not only the environment that acts on the organism; the organism also in some measure changes its environment. Sometimes this change occurs on a large, cosmic scale—the entire biosphere of the given planet changes, and this can be determined in some way or other by astronomical observations; in other cases the changes are of a local nature and external observation may create the impression that the organisms exist under intolerable conditions.

Such phenomena may be observed even as regards organisms on a very low rung of the evolutionary ladder, for example, microbes. One of the authors of this book happened to observe the following in his experiments. On sugar-beet roots kept in a refrigerator for many days at a constant temperature of —5°, —7°C the experimenter sometimes observed the development of moulds which seemed to ulcerate the surface of the roots. The temperature taken with a microthermocouple directly in the lesions turned out to be around +15°C despite the general low temperature of the refrigerator and the roots. The micro-organisms themselves created the temperature they needed by locally heating the hole they occupied in the root with the heat isolated during the oxidation of sugar in the process of breathing.

It is well known from micro-biological literature that microbes may be cooled to the temperature of liquid air and even lower. In this case the rate of their biochemical reactions approaches zero and they enter a state of anabiosis. But after a careful warming-up they regain their vital activity. Similar phenomena are observed in spores surviving high temperatures (100°C and over) and in the complete exsiccation of a number of organisms, plant seeds, etc.

In all these cases we are dealing with an adaptation, which enables the organism to survive under unfavourable external conditions and come back to life when the conditions change. This makes it possible to preserve life under very considerable fluctuations of temperature, humidity, etc. But the case described above differs essentially from this sort of survival in that in this case we do not have a cessation of vital activity, but, on the contrary, as a result of this vital activity the organism creates the conditions it requires in a very limited area of habitation.

Analogous phenomena are created in the so-called spontaneous heating of hay, peat, manure, compost, etc. It has been established that the thermophilic (heat-loving) micro-organisms, which develop in these materials, themselves actively participate in the creation of the temperature conditions in the spontaneously heating masses. In these cases the temperature may reach 50-70°C and more. This results in a situation which favours the development of the thermophilic organisms and causes their competitors with a lower temperature optimum to perish. It can be observed in the spontaneous heating of stored grain that the microbes not only create a favourable temperature, but also substantially raise the humidity necessary to life at the expense of the water formed during the oxidation of starch.

It should be noted that the more highly organized the given living being, the higher it has climbed in its evolutionary development, the more actively can it emancipate itself from the unfavourable external conditions. Its relations with the outside world expand and become differentiated, but it creates its own internal environment and thus extraordinarily extends its possibilities of existing under diverse conditions.

This can be observed at least in warm-blooded animals. Their body cells and, especially, their nervous tissues, are extremely sensitive to even the slightest fluctuations in temperature, to changes in acidity, salt content, oxygen supply, etc. But the animals can live under very unfavourable external conditions (for example, in the Extreme North) because they have their own internal environment, where all of the above-mentioned factors are regulated with amazing precision.

Man presents an absolutely exceptional case in this respect because at the time of his descent matter had already transcended in its development the biological evolution, had risen to a higher stage and had acquired new social forms of motion.

In our days, when technical projects of an artificial satellite for the Earth are actually being developed, hardly anybody will doubt that man will be able to live on this satellite and, hence, say on the Moon, where the external conditions are extremely unfavourable to life.

But the answer to whether life could have originated on the Moon in the process of its cosmic evolution with man as the result of this development will be quite different. All we know about the nature of the Moon today makes us answer this question in the negative.

However, the problem of the existence of life throughout the Universe is formulated in an approximately analogous manner. We have good reasons for rejecting the panspermic theory, which asserts the possibility of constant transfer of viable germs from one celestial body to another, and believe that life originates anew in the process of the development of matter each time and wherever the requisite conditions for this origin are on hand. This is why we cannot reduce our analysis only to a simplified comparison of the physical and chemical conditions which now exist on any particular celestial body and which are required by any of the terrestrial organisms to live on it.

To get the answer we need we would have to picture to ourselves the ways life originated and developed on a given celestial body in the process of its evolution, as we did here on the Earth, or on the contrary, trace the course which has led the development of the given celestial body away from the possibility of living organisms forming on it. The solution of the problem posed in this manner is extraordinarily complicated by our meagre knowledge in cosmogony and, to a certain extent, in the problem of the origin of life. But the need is already ripe for a general survey of all the data we possess and at least for the most preliminary summaries in this field.

The analysis of the elements, which compose the bodies of the plants and animals inhabiting the Earth, as it has been made by V. Vernadsky and his pupils, warrants two very important inferences. In the first place, we do not find in the organisms any elements which are not peculiar to the Universe generally, and, secondly, the quantitative correlations of the elements of which the living bodies are composed sharply differ from the corresponding correlations in the Galaxy as a whole and differ somewhat even from the environment in which the organisms live. In the total mass of organisms an average of 70 per cent of the full weight falls on oxygen, 18 per cent on carbon and 10.5 per cent on hydrogen.

Thus, the elements of water and carbon, which form the basis of organic substances, prevail quantitatively in the composition of living organisms. They constitute a sum total of more than 98 per cent of the live weight of organisms. The remaining 1.5-2 per cent include nitrogen, calcium, potassium and silicium which enter the composition of the living organisms in tenths of one per cent, and phosphorus, magnesium, sulphur, chlorine, sodium, aluminium and iron, which form only hundredths of one per cent. All these elements together with oxygen, carbon and hydrogen constitute 99.99 per cent of living substance. The numerous remaining elements of the periodic system participate in the building of living substance in thousandths and even millionths of one per cent. Many of these do not necessarily have to be present in every organism and are only typical of certain groups of living beings. Thus, for example, vanadium is concentrated in the blood of a highly specialized group of marine animals—ascidia, where it plays an important physiological part similar to that of iron or copper in other organisms.

The elementary composition of living organisms we have considered shows that water is their simplest and at the same time quantitatively prevailing chemical constituent. It plays an important part not only as the medium in which the metabolic processes take place, but also as a chemical compound which directly participates in very important biological reactions.

We are pretty well aware of the biological role of the compounds which form other numerous (so-called ash) elements. Some of them take part in building the proteins of the protoplasm, others form part of the biological catalysts—ferments, still others set up the specific physical and chemical conditions on which both the structure of protoplasm and the sequence of the biochemical process, which take place in it, depend.

But whatever the role of water and ash elements in the composition of life's substratum, organic substances play the most important part. They are specific compounds of the living world. Not only do we not know a single living being without organic compounds, but we cannot even theoretically conceive the process of metabolism, specific to life, without them.

We must, therefore, consider the formation of organic substances the first stage in the general development of matter on the way to the origin of life. Hydrocarbons are the simplest and, in this respect, initial compounds. It is not without reason that organic chemistry is now regarded as chemistry of hydrocarbons and their derivatives.

Even this first stage in the development of matter on the way to the origin of life was until relatively recent times regarded in scientific literature as something incomprehensible and unknowable. As a matter of fact the transition of inorganic forms of carbon into organic forms at the present stage of the Earth's existence takes place almost exclusively biologically, mainly in the process of photosynthesis. By utilizing the energy of sunlight green plants synthesize all the organic substances they need for life and growth at the expense of the inorganic compound of carbon (carbon dioxide). Animals get these substances from plants either through direct consumption or through consuming herbivorous creatures, their corpses or remains. The same source of nourishment may be established for the overwhelming majority of the other micro- and macro-organisms, parasites and saprophites. Only a very limited group of colourless microbes is able independently to create organic substances from carbon dioxide utilizing for this purpose the energy of oxidation of reduced compounds of sulphur, iron or nitrogen (chemosynthesis), but here, too, we have a biogenic formation of organic substances.

Consequently, all the organic substances of the modern living world on our planet are formed biogenically—by organisms. The same course lies at the basis of the origin of coal, oil, bitumens and other organic fossils formed as a result of decomposition of the organisms which had at one time inhabited the Earth. Many naturalists have, therefore, but recently rejected any possibility of abiogenic formation of organic substances under natural conditions, and this very much impeded the solution of the problem of the origin of life.

A profound study of the question has shown, however, that the biogenic mode of formation of organic substances prevailing on our planet today is characteristic only of the modern epoch of its existence. It has formed as a result of a long evolution of organisms, which had at one time originated on the Earth; but organic substances had also formed on the Earth long before these organisms lived on it.

D. Mendeleyev demonstrated the possibility of such formation of hydrocarbons by interaction between carbides and water.

It is well known that carbides of metals, particularly, carbides of iron, nickel and cobalt were found in the composition of the Earth's crust many years ago. In his time A. Fersman voiced an assumption that such carbides composed the main mass of the Earth's central core. At any rate they form one of the deepest layers, sometimes coming to the surface, however, where they can directly interact with water. V. Vernadsky had already pointed out that such processes were actually possible in the Earth's crust under modern conditions; this possibility was recently fully confirmed by reports published in geological literature that hydrocarbons of abiogenic origin had been found in igneous rock.

Consequently, abiogenic formation of the simplest organic compounds—hydrocarbons—is taking place on the Earth even today, and it undoubtedly occurred on a wide scale in the past, especially, in the process of the formation of our planet.

On the basis of his extensive physicochemical investigations H. Urey came to the conclusion that during the formation of our planet from a proto-planet a considerable part of the primary methane of the gas and dust cloud (which, according to modern views, served as the material for the formation of the planets) volatalized owing to a temperature increase in the region where the terrestrial planets were being formed. Carbides of iron and nickel alloys offered the form for carbon accumulation at the time. Subsequently, when the formation of the Earth was nearly completed, but the Earth was still in its reduction stage, new hydrocarbons, emitted from the entrails of the planet into its atmosphere, were being formed.

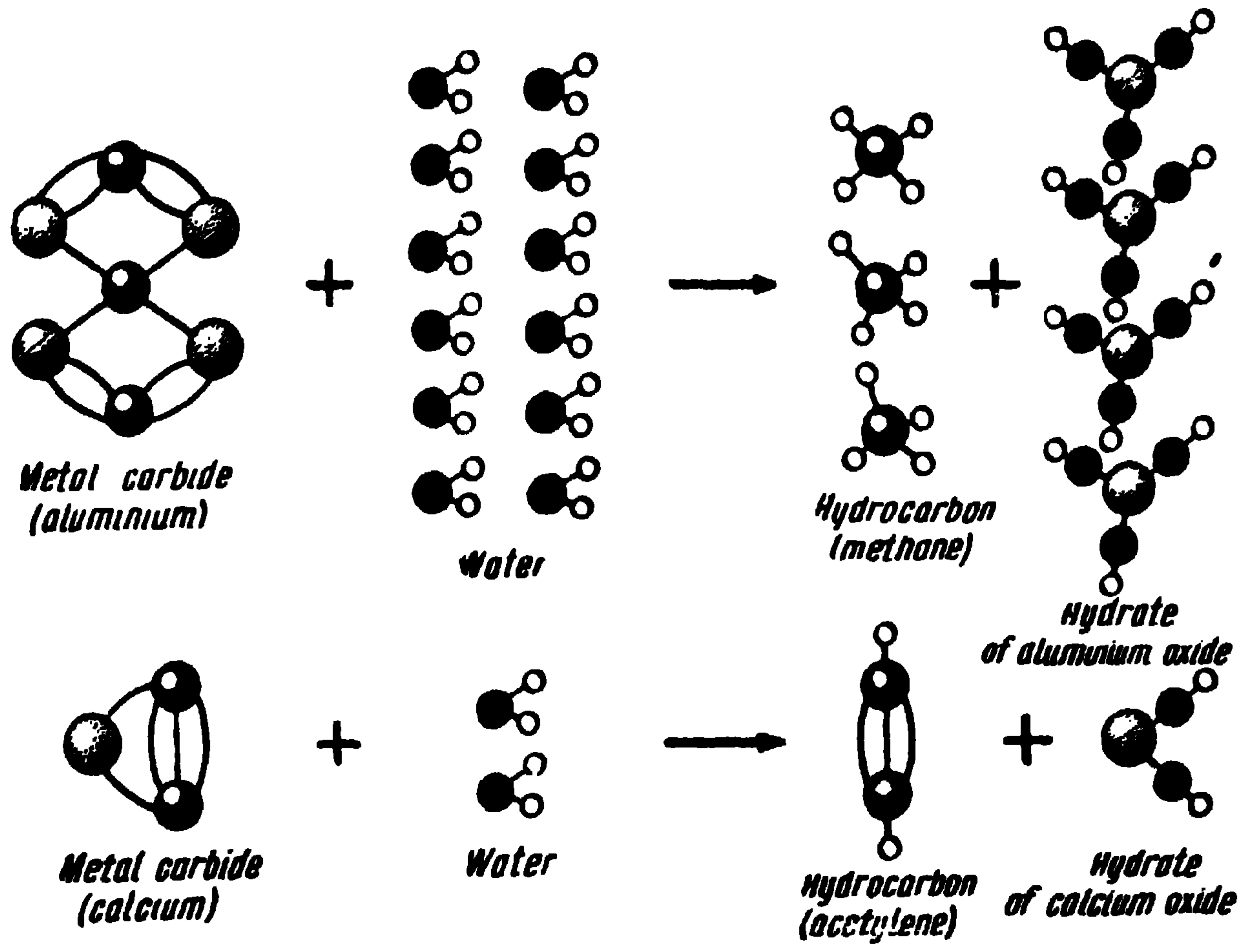

Fig. 1. Diagram of hydrocarbon formation from interaction between metal carbides and water

Our knowledge in the field of stellar and planetary cosmogony is still very insufficient, but we are warranted in the assertion that the main condition for the first stage in the development of matter on its way to the origination of life—the formation of hydrocarbons on any particular celestial body—was the reduction medium. As a matter of fact, inasmuch as hydrogen is the predominant element throughout the Galaxy, we can ascertain the presence of hydrocarbons everywhere, on the most diverse celestial bodies and under the most different physical conditions. We discover compounds of carbon and hydrogen in the atmosphere of the stars, in particular, in the atmosphere of our Sun, at a temperature of several thousand degrees. Methane is present in enormous quantities in the atmosphere of the large planets, where there is a very low temperature, but where the relationship of the elements is preserved on the level which existed in the primary gas and dust cloud with a sharp prevalence of hydrogen and, consequently, with a clearly pronounced reduction nature. As we have mentioned above, hydrocarbons were isolated directly from meteorites, while the bands characteristic of them were discovered in the spectra of comets. Hydrocarbons must, undoubtedly, have formed on other terrestrial planets as they did on the Earth.

Thus, the stage in the development of matter, which we may regard as the first very important stage on the way to the origin of life on the Earth, is a widespread process in the Universe and is peculiar to a large number of different celestial bodies.

The second stage on this way is somewhat different. This stage on the Earth was the process of the origination of various and complex organic compounds forming part of living organisms, especially the origin of protein bodies which crown the chemical evolution of organic compounds and at the same time play an extremely important part in the life of all organisms without exception. The presence of hydrocarbons was the initial and necessary condition for going through this stage, since it is precisely hydrocarbons that are fraught with extremely wide chemical possibilities and at the same time possess the enormous reserve of energy required for the formation of complex and high molecular organic compounds of the living world.

However, these concealed potentialities of hydrocarbons could be realized only during the transition from the reduction stage to a more oxidized stage in the existence of the planet. At this stage the Earth had already lost its primary hydrogen. Due to photochemical reactions in the upper layers of the atmosphere the vapours of water broke up into oxygen and hydrogen. Because of its relatively small mass the Earth was unable to retain the hydrogen and the latter escaped into the inter-planetary space, while the oxygen joined the substances which were as yet unsaturated with it and formed part of the lithosphere and the atmosphere. The ammonia present there was oxidized into molecular nitrogen, while methane and the other hydrocarbons changed into such organic oxides as alcohols, aldehydes, ketones and organic acids all the way down to carbon dioxide, the final product of oxidation. A similar process may have occurred during direct hydration of the hydrocarbons as a result of their com-

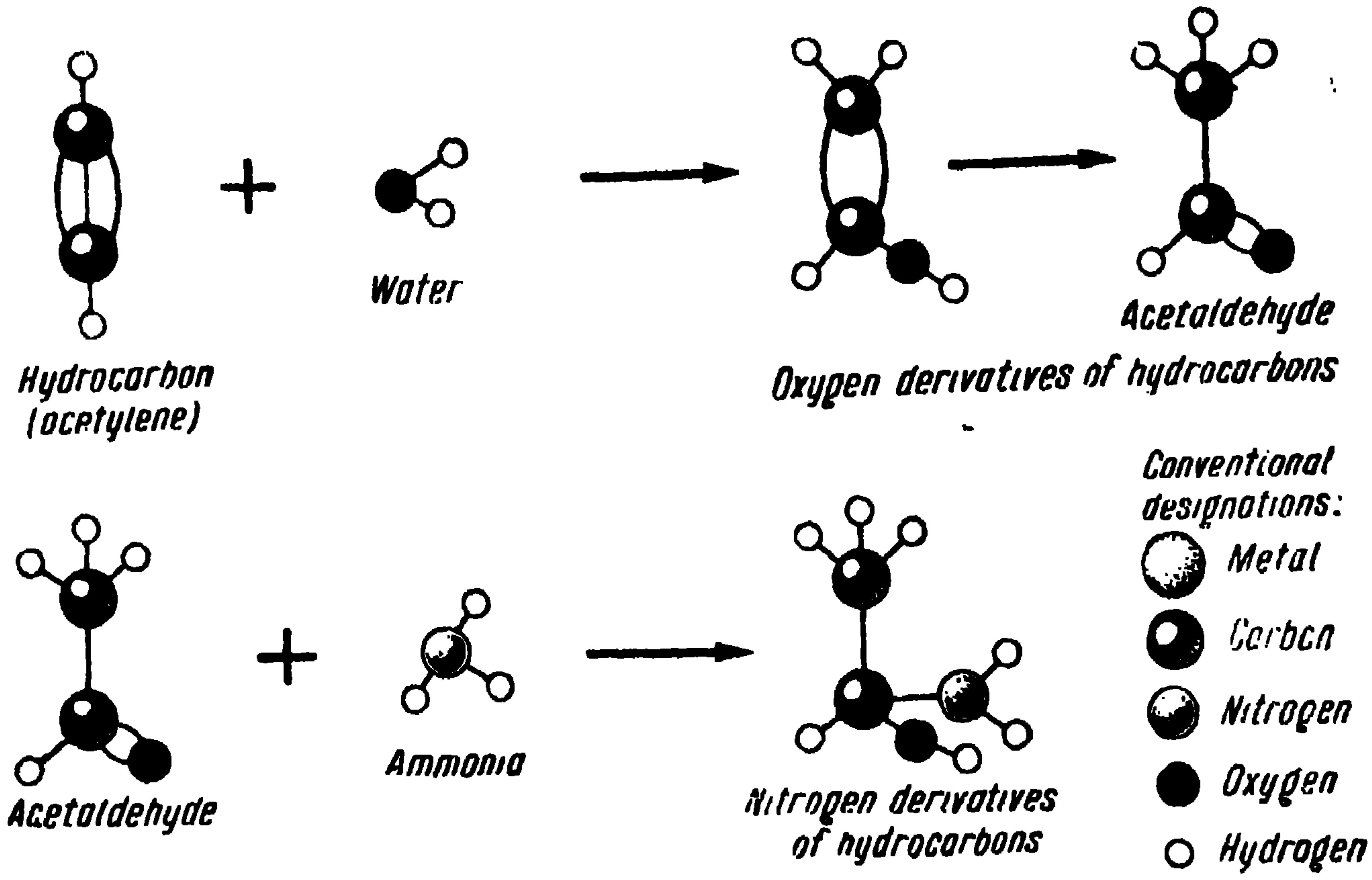
Hydrocarbon (acetylene)
+
Water
Oxygen derivatives of hydrocarbons
Acetaldehyde
Conventional designations:
Metal
Carbon
Nitrogen
Oxygen
Hydrogen
Acetaldehyde
+
Ammonia
Nitrogen derivatives of hydrocarbons

Fig. 2. Diagram of hydrocarbon hydration and addition of nitrogen

bining with whole molecules of water. As a result of their interaction with ammonia the aforesaid organic compounds yielded nitrous derivatives of hydrocarbons along with their oxygen derivatives.

From the humid atmosphere these compounds had to pass to the hydrosphere of the Earth, and we can judge about their subsequent transformations on the basis of modern chemical research.

The sum total of the data of organic chemistry shows that while the low molecular hydrocarbons and their oxygen and nitrous derivatives are in a humid atmosphere or in an aqueous solution they go through a far-reaching polymerization and condensation, which leads to the formation of very complex substances, closely resembling those that are found in the composition of living organisms. Due to the high-energy level of the initial materials these processes are of an exothermic nature and occur freely in homogeneous solutions at the usual, rather low, temperature.

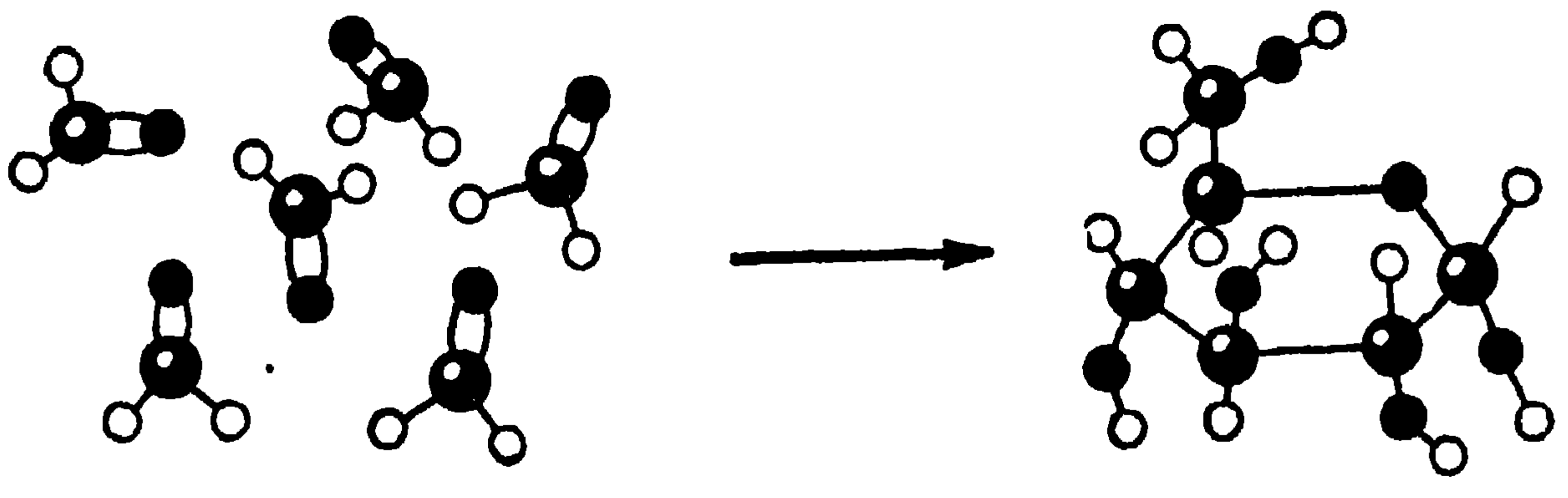

Fig. 3. Diagram of formation of sugar from formaldehyde

It is very easy to demonstrate the possibility of formation of sugars and other carbohydrates in the Earth's primary hydrosphere on the basis of A. Butlerov's, E. Fisher's, O. Löw's and G. Euler's investigations. These scientists synthesized sugars by simply keeping an aqueous solution of formaldehyde in the presence of small amounts of lime or chalk as catalysts.

Many recently published works show that such complex and, at the same time, widespread substances in organisms as porphyrines, nucleotides, etc., have been likewise synthesized from the simplest carbon and nitrogen compounds.

We are particularly interested, however, in the origin of albuminous substances in the Earth's primary hydrosphere.

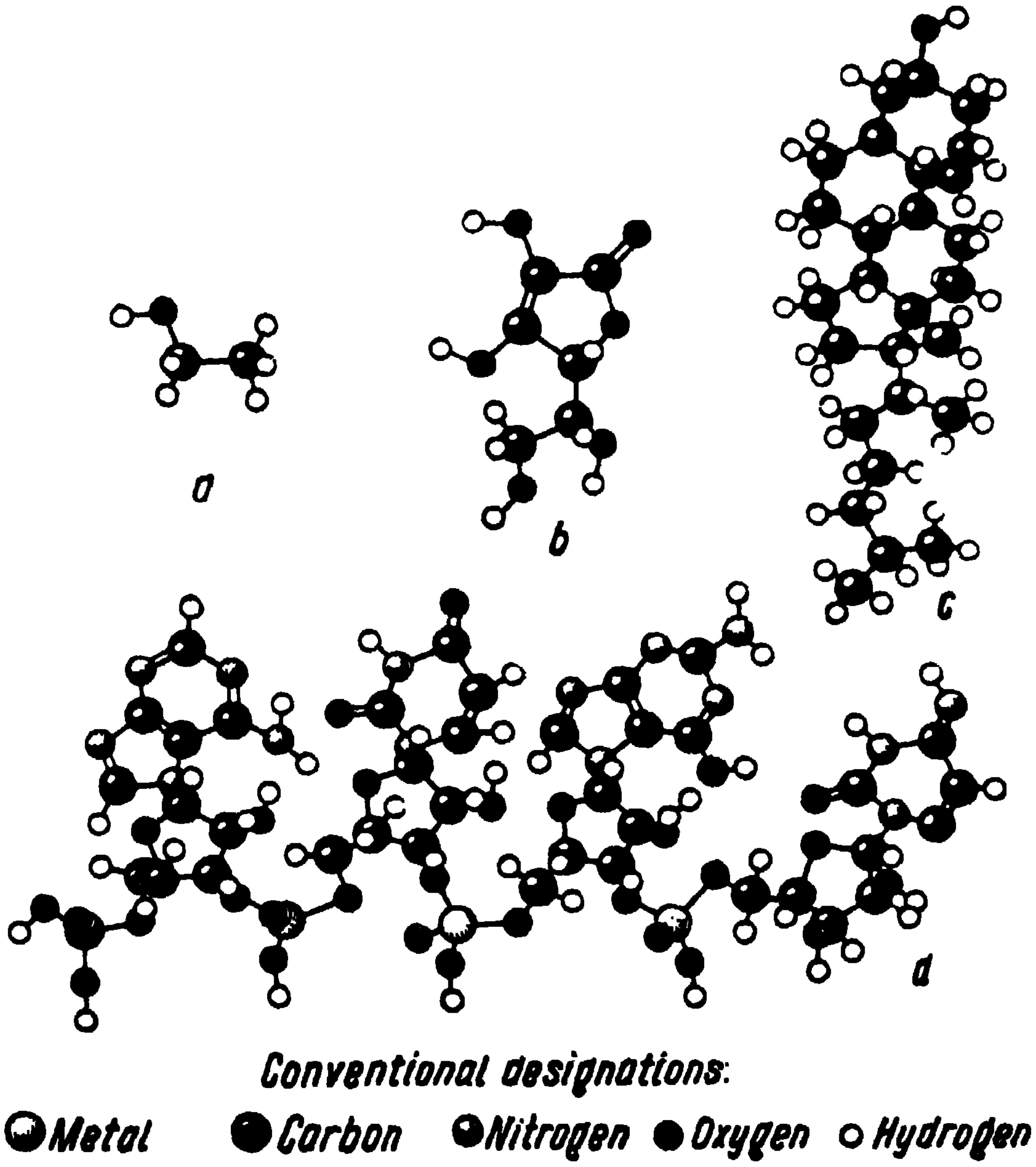

Fig. 4. Diagram of the structures of molecules of different organic substances: a. Alcohol, b. Vitamin C, c. Fatty substance (cholesterin), d. Nucleic acid

To answer this question it is first necessary to show the possibility of formation of amino acids—the principal links in the formation of a protein molecule—and then find out how these links were able to form a polypeptide chain, which lies at the basis of this molecule.

In the field of amino-acid synthesis we now have direct experimental data. We must mention, in particular, the work of S. Miller who, on the basis of A. Oparin's ideas and H. Urey's data, passed electrical sparks through a mixture of methane, hydrogen, ammonia and water vapours. By using the method of paper chromatography several days later he was able to detect glycine, alanine and other amino acids in the solution. A repetition of these experiments at the Institute of Biochemistry of the U.S.S.R. Academy of Sciences not only fully confirmed Miller's results, but has also demonstrated the possibility of partly replacing methane by carbon monoxide. It stands to reason that in all such syntheses the amino acids and other complex organic substances are obtained in the form of racemates.

It is well known that many organic substances can exist in two forms which are very much alike. Their molecules are made up of the same atoms and even of the same atom groups, but these groups are differently distributed in space. If a radical of one form of an analogous compound is located on the right, exactly the same radical of the second form is located on the left and vice versa. Our two hands may serve as a generally comprehensible model of these dissymmetric molecules. If we place them, palms down before us, we will see that the right and left hands differ profoundly as to the location of their parts. While the thumb of the right hand is directed to the left the thumb on the left hand is directed to the right. Each hand is, as it were, a mirror reflection of the other.

In an artificial synthesis of organic substances we always obtain an even mixture of both forms of disymmetric molecules (racemate). This is quite understandable, since the formation of either of these forms—right or left antipodes—in a chemical reaction depends on which of the two atoms or radicals located to the right or left of the plane of symmetry, will be replaced by new atomic groups. But both these atoms or radicals are acted upon by perfectly identical forces, and either of the antipodes can, therefore, form with the same probability. As a matter of fact, no excess of either antipode or so-called asymmetry, is ever observed in artificial syntheses.

Contrariwise, asymmetry is the most characteristic feature of living organisms. Here we always encounter the formation and accumulaton of one of the antipodes. In particular, the amino acids, which form part of natural proteins, are always represented only by the left-side form.

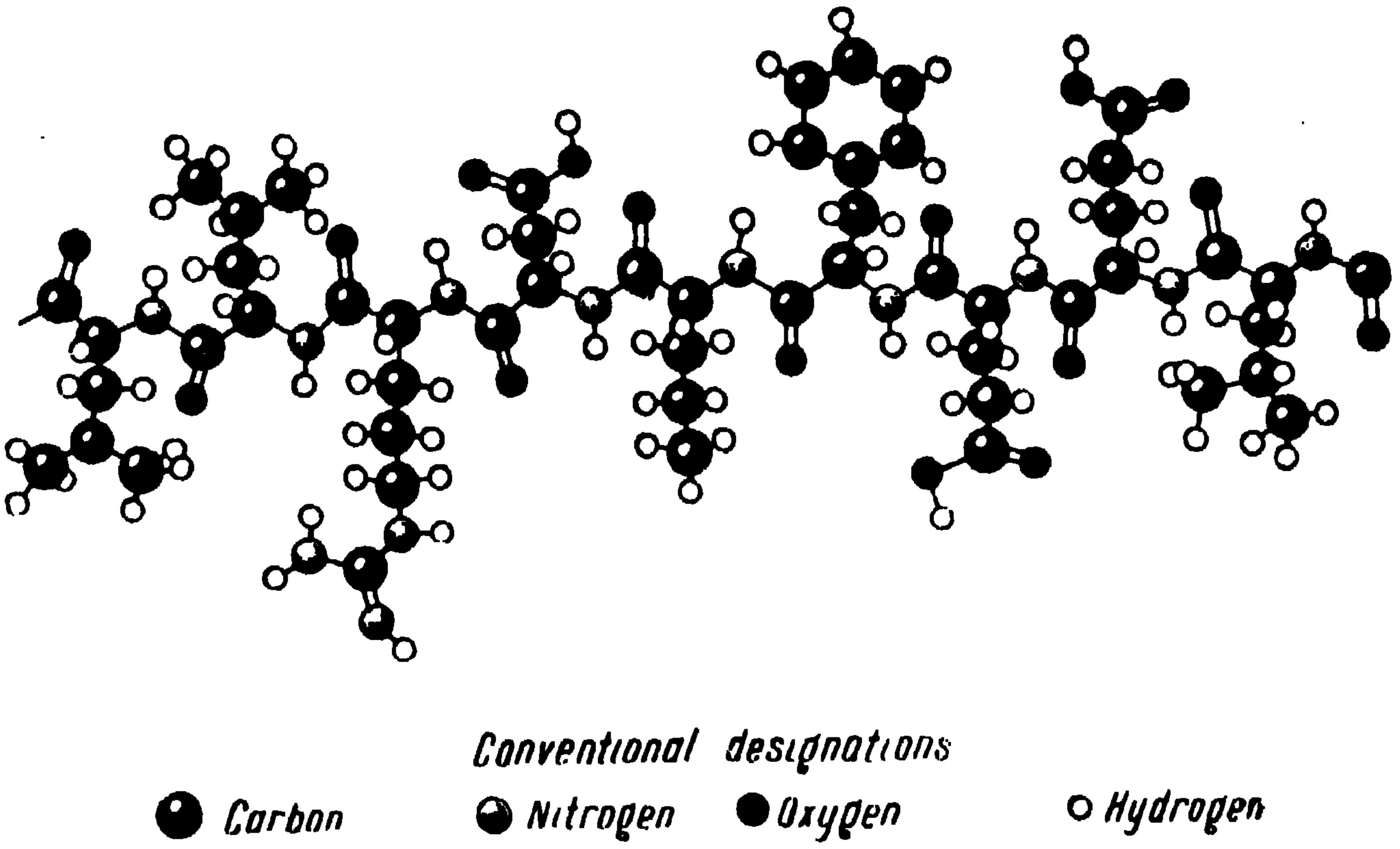

Fig. 5. Diagram of a small section of a polypeptide chain forming the basis of the protein molecule

The question of the impossibility of an asymmetric synthesis other than through living organisms was very acute early in the 20th century and seriously impeded the solution of the problem of the origin of life. But already Pasteur pointed out the possibility of using for an asymmetric synthesis not only asymmetric substances, but also some natural asymmetric physical factor. Such a factor was subsequently really found in inorganic nature in the form of circularly or elliptically polarized light. By using it in photochemical reactions it was possible to obtain only one optical antipode of certain organic substances.

In this case light necessarily had to take part in the synthesis of complex organic substances on the Earth. But in his book *Physical Bases of Life* J. Bernal showed another much more perspective course for the primary origination of asymmetry in nature. It is the reaction on the surface of optically active crystals of quartz very common in inorganic nature. Recently A. Terentyev and his associates achieved a direct (absolute) asymmetric synthesis of a number of organic substances catalyzing the reactions of hydration, isomerization, etc., on the surface of quartz.

A very great difficulty in the way of the primary synthesis of proteins under the conditions of the Earth's initial hydrosphere was the energy barrier which has to be overcome in the polymerization of amino acids into polypeptides. The basis of a protein molecule is formed by chains whose separate links are amino-acid particles connected among themselves by so-called peptide bonds. It has been calculated that a considerable outlay of energy (about 3,000 cal/mol) is required for the formation of peptide bonds between the amino-acid radicals. In an ordinary water solution of amino acids this reaction practically takes no place as it does in Butlerov's reaction when sugar is formed from formaldehyde. K. Linderström-Lang suggested, however, that when a large peptide is synthesized from an amino acid and another peptide the free energy outlay may be considerably lower than 3,000 calories. This was experimentally confirmed by A. Dobry and J. Fruton. On the basis of his experiments the latter concludes that the value ΔF depends on the nature of the components entering into the reaction owing to which it varies very widely, sometimes dropping to only 400 cal/mol. In most cases the reactions of peptide syntheses are endoergic, though cases of exoergic synthesis are also known. Fruton further points out that the reactions, in which the products obtained are isolated from the total solution passing into an insoluble state, offer considerable prospects for increasing the emergence of peptide. This is the case, for example, when glycinamide is replaced by glycinanilide. The emergence of peptide reaches 65 per cent. Fruton sees one of the principal ways for a far-reaching lengthening of the polypeptide chains in transpeptidation and transamidation —reactions which do not require considerable outlays of energy.

Many hypotheses concerning the sources of energy required for the synthesis of polypeptides and diagrams of coordination of energy reactions have appeared in scientific literature of late. As an example we can point at F. Lipman's hypothesis on the participation of the transphosphorylating ATP[1] reactions, based on experiments with the synthesis of glutathion. A very interesting hypothesis of the primary protein synthesis was recently suggested by the Japanese scientist S. Akabori.

The investigations conducted by S. Bresler in the last few years are especially significant. Allowing for the fact that the outlay of free energy for the creation of a peptide bond in an aqueous solution may be compensated by a diminution of free energy due to the action of external pressure, Bresler made his syntheses under pressure of several thousand atmospheres. He synthesized peptide bonds in the presence of corresponding ferments and obtained high molecular polymers of amino acids in some respects resembling albuminous substances. The unsuccessful experiments in analogous syntheses recently conducted by Talwar and Machbeuwf call Bresler's data in question, though the latter very plausibly explains these failures. This controversy will, naturally, be settled by subsequent experiments, but if Bresler's syntheses are confirmed they will be of extreme importance to our problem since they show the thermodynamic possibility of a synthesis of albuminous substances under the conditions of the high pressures which are easily set up even in the outer shells of the globe (for example, at great ocean depths). Thus, while there are still many gaps in our knowledge concerning the second stage, we have mentioned, in the development of matter and we need extensive and complex experimental work to meet the deficiency, the general nature of the processes which resulted in the primary synthesis of proteins and other complex organic compounds on the Earth is already quite clear.

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[1] ATP—adenosine triphosphoric acid, a compound abounding in energy (macroergic compound).

What conditions were required for similar processes to occur on other planets and what could have hindered them?

The first requirement—the presence of initial hydrocarbons, as we have observed, was met by many planets. The case is somewhat different with the second requirement—the origin of the oxidation stage. This stage can appear only when a planet, owing to its small mass, cannot retain the free hydrogen and considerably changes in the process of formation and development its elementary composition as compared with that of the initial gas and dust cloud. But this could not have taken place on the large planets which have almost fully retained their primary hydrogen. There the evolution of hydrocarbons took a different course. In part, reactions of photochemical polymerization of methane leading to the formation of high-molecular saturated and unsaturated hydrocarbons might have occurred extensively on the large planets. Thus, for example, the colouring of the red spot on Jupiter is ascribed by some astronomers to the highly polymeric compound—cuprene. But the hydrocarbon derivatives characteristic of living organisms could not have originated there. Only the terrestrial planets met the second requirement we have mentioned.

An indispensable presence of water may be considered the third requirement. Water is necessary as a direct participant in the hydration reaction and the irreplaceable medium in which the aforesaid transformations of hydrocarbons and their derivatives may take place. On the Earth all these processes occurred in the hydrosphere; the presence of large reservoirs on the surface of the Earth also aided in the migration of many ash elements necessary for the formation of a number of compounds and for the catalysis of most of the chemical reactions; calcium in the process of sugar synthesis and iron in the catalysis of oxidation reactions may serve as examples.

But it cannot be denied that processes are also likely to occur outside large accumulations of water. Some scientists (W. Williams and N. Kholodny) even supposed that life on the Earth originated on the surface of the particles of marl of primordial rocks. This point of view was supported by B. Polynov, who had made an extensive study of the problems of migration of the elements of the biosphere.

In order that the processes we have mentioned take place on the surface of the rock particles, these particles must be moistened with water present either in the form of drops or at least as surface films. Only under these conditions, in water just the same, could the formation of complex organic substances, particularly proteins, have taken place. It is clear that under these conditions the amount of water required sharply diminishes.

The afore-named scientists advanced their hypotheses mainly because in the particles of marl they saw protection for the proteins and primary organisms against the destructive action of cosmic radiation, mainly the short-wave ultra-violet rays. As a matter of fact proteins intensively absorb ultra-violet rays especially within the limits of 2,700-2,800 Å. With the subsequent shortening of the waves 2,600-2,400 Å their absorption capacity somewhat diminishes and then rapidly increases again. The absorption of light is paralleled by a denaturation of proteins connected with their profound chemical changes. Today the proteins of organisms are protected on the Earth by the ozone screen present in the atmosphere. During their formation in oceanic waters the protein substances could have been preserved because the ultra-violet rays were absorbed by the upper layers of water. At any rate the destructive action of short-wave radiation must be taken into account in our judgements of the way of proteins formation on different celestial bodies.

We must now touch upon the temperature requirements. Owing to their exothermic nature the reactions we have considered could have taken place more or less rapidly within rather wide limits differing by dozens of degrees in either direction from the average terrestrial conditions of today. But could the proteins have originated and survived under relatively high temperatures or should they have undergone thermal denaturation? This question is much more complicated than it is usually believed to be. It is ordinarily thought that proteins coagulate at 60°C, but this is a prejudice based on the everyday observations of the coagulation of the egg-white. As a matter of fact most of the plant and animal proteins we know denature at much lower, even under so-called room temperatures. This is why we must do this work in refrigerating chambers if we wish to obtain a preparation of non-denatured protein in our laboratories. The question is: how can native protein exist under terrestrial conditions, especially in warm-blooded organisms, in thermophilic bacteria and in the microbes that live in hot springs at temperatures of about 90°C? This paradox is, apparently, partly explained by the fact that the thermostability of proteins considerably increases when the latter combine with certain substances, for example, nucleic acids, hemin, etc. But on the whole this problem cannot be considered fully solved even for our terrestrial conditions.

Thus, we see that the second stage in the development of matter on the way to the origin of life already required much more differentiated conditions than the first. These requirements could be met only by some celestial bodies, in particular, the planets of the terrestrial group of the solar system and analogous planets of other stars.

We sometimes hear that with the formation of proteins as the most complex organic compounds, with the formation of the high-molecular amino-acid polymers the process of the origin of life may be considered ended. References are frequently made to well-known statements of F. Engels, overlooking the fact, however, that Engels did not speak simply of protein, but of protein bodies endowed with metabolism, bodies which in order to exist must constantly regenerate themselves at the expense of the substances in their external environment.

We do not find this process of self-regeneration and self-reproduction anywhere in the inorganic world. It is, therefore, metabolism that is the characteristic feature of life and that compels us to regard it as a qualitatively specific form of motion of matter.

Even the simplest organism lives only as long as ever new particles of substance and the energy peculiar to it move through it in a constant stream. From its environment the organism absorbs extraneous, foreign substances, which as a result of a series of biochemical reactions are transformed into the substances of the organism itself and become identical with the chemical compounds which had previously already formed part of the living body. This is the process of assimilation, but it goes on hand in hand with dissimilation, the reverse process. The substances of a living organism do not remain invariable, but disintegrate more or less rapidly and are replaced by the newly assimilated substances while the products of disintegration are voided into the external environment. Thus, the substance of a living organism continually disintegrates and regenerates as a result of numerous closely interconnected reactions of decomposition and synthesis.

The sum total of modern biochemical knowledge shows that the separate individual reactions taking place in living bodies are relatively simple and uniform. These are the well-known reactions of oxidation, reduction, hydrolysis, phosphorolysis, aldol condensation, transamination, etc., easily reproduced in the chemist's retort.

There is nothing specifically vital in any of them. Specific for living bodies is, primarily, the fact that in them these separate reactions are in a certain manner organized in time and combined into a single integral system, like separate sounds combining into a musical composition, for example, a symphony. No sooner do we disturb the sequence of sounds than we get disharmony and chaos. It is likewise important for the organization of living bodies that the reactions in them occur not accidentally or chaotically, but in a strictly established harmonious order which lies at the basis of both anabolism and catabolism. Such vital phenomena as, for example, fermentation, respiration, photosynthesis, synthesis of proteins, etc., are long chains of reactions of oxidation, reduction, aldol condensation, etc., which replace each other in a perfectly precise sequence, in a strictly established, regular order.

But what is particularly important, what fundamentally distinguishes the living organisms from all the systems of the inorganic world, is the purposefulness of the afore-said order peculiar to life. Many scores and hundreds of thousands of chemical reactions taking place in a living body not only harmoniously combine in a single order, but the entire order regularly conditions the self-preservation and self-reproduction of the vital system as a whole under the given conditions of the external environment and in a surprising conformity with these conditions.

The origin of metabolism, the formation of protein bodies endowed with metabolism, i.e., essentially the formation of the simplest living organisms, was the third, decisive stage in the process of the origin of life on our planet.

A careful study of metabolism in modern organisms at different stages of evolutionary development shows that the rates of the separate chemical reactions, which lie at the basis of the phenomena peculiar to metabolism, are closely co-ordinated. Any organic substance can react in very many different directions and has extensive and multi-form chemical possibilities, but outside of living matter these possibilities are realized extremely slowly. Contrariwise, in living organisms organic substances react very fast (though the speed differs in separate cases), which creates the conditions for the definite sequence and co-ordination of the reactions against the background of the stormy process of life. The reason lies in the catalytic properties of proteins. In order that any substance of a living organism take real part in metabolism it must interact chemically with protein, form with it a definite, very mobile and unstable intermediate compound. Otherwise its chemical potentialities will be realized so slowly that the importance of the given reaction to the process of life will be lost.

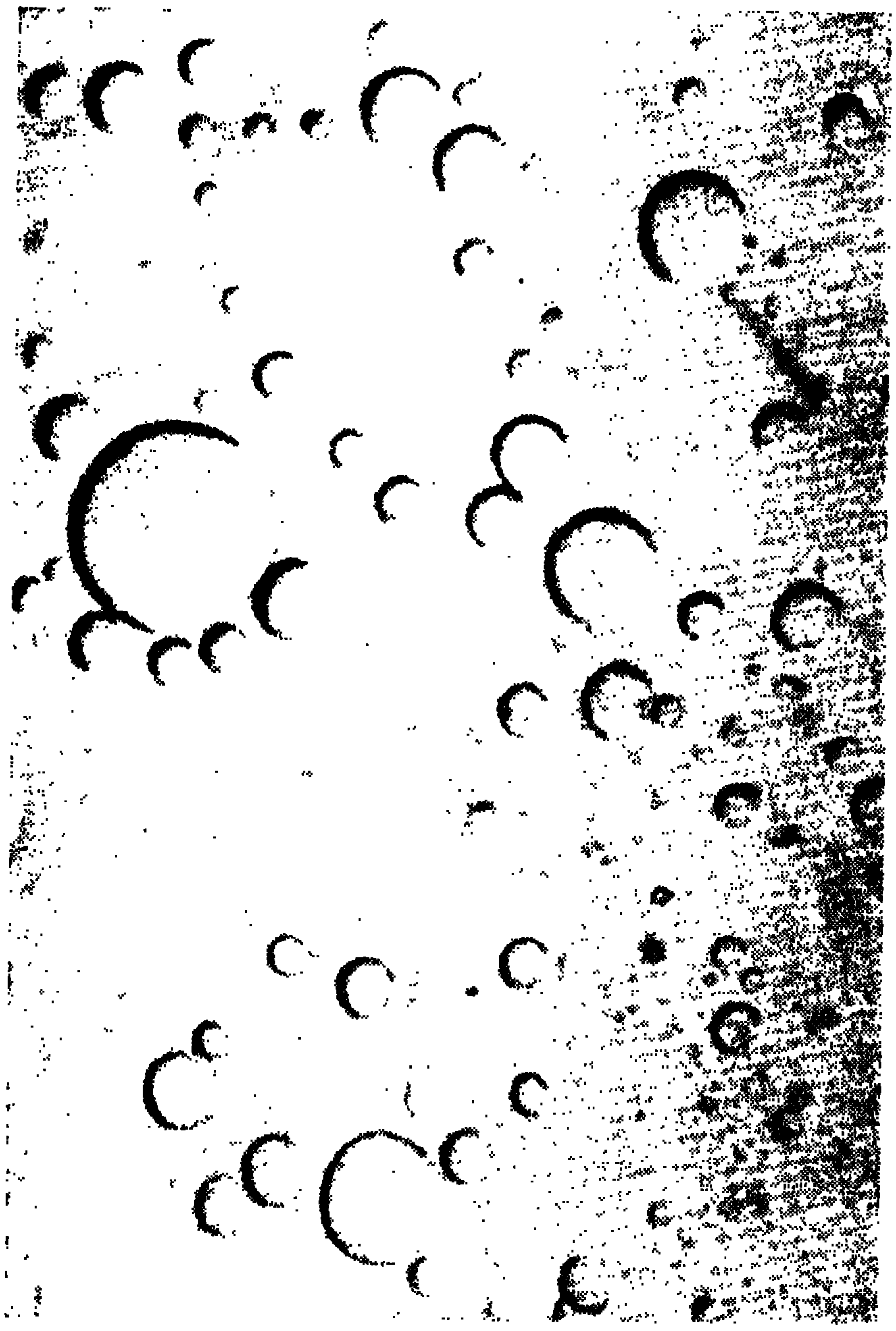

Fig. 6. Relatively simple two-component coacervate drops magnified 225 times

Thus, in proteins (ferments) living matter has not only powerful accelerators of the chemical processes, but also the internal apparatus which gives these processes a very definite direction. Since the protein ferments are extraordinarily specific, each of them can form intermediate compounds only with certain substances and catalyze only strictly definite individual reactions of hydrolysis, oxidation, condensation, etc. Hundreds and thousands of various protein-ferments, combining into an intricate and at the same time single complex, take part in every vital process, the more so in the total metabolism.

Hence, it is clear that on the way to the origin of life there must have formed analogous, multi-molecular protein complexes which were isolated from the general solution of the protein substances as individual systems—protein bodies.

Most of the modern scientists, who devote themselves to the problem of the origin of life, see the necessity for the isolation of such systems mainly in the fact that their origin consolidates, as it were, the result of the protein synthesis, that they are in lesser measure subject to the reverse process of disintegration.

Wald says that the isolation of protein complexes created the conditions under which the "intra-molecular disintegration was counteracted by different inter-molecular aggregation." It appears to us that this manner of isolation of specific protein systems was even more important in respect to new regularities of a higher order than the ones governing the phenomena in the inorganic world were, as we shall subsequently show, created on its basis.

Diluted solutions of low molecular substances are quite stable systems in which the degree of diffusion of the substance and the uniformity of its distribution in space are not in themselves disturbed. On the contrary, particles of high molecular proteins yield colloidal solutions which are relatively unstable. If we mix two or more solutions of individual protein substances under very simple ordinary conditions we shall observe a pronounced turbidity in the mixture. If we examine this turbid liquid under a microscope we shall see that in the formerly vacant field of vision some sharply defined drops have formed and now float in the surrounding liquid. The following is taking place: the protein molecules formerly evenly distributed throughout the solvent begin to unite into molecular swarms or piles and, when one of these piles reaches gigantic proportions, when it contains many millions of molecules, it separates as the drop we see under the microscope. These drops have been termed coacervates (from the Latin word *coacervatus*—accumulated, collected). All the proteins formerly diffused in the solution now concentrate in these drops, while the surrounding liquid is essentially deprived of these substances; it is now water or a solution of the low molecular substances which have not entered into the coacervate.

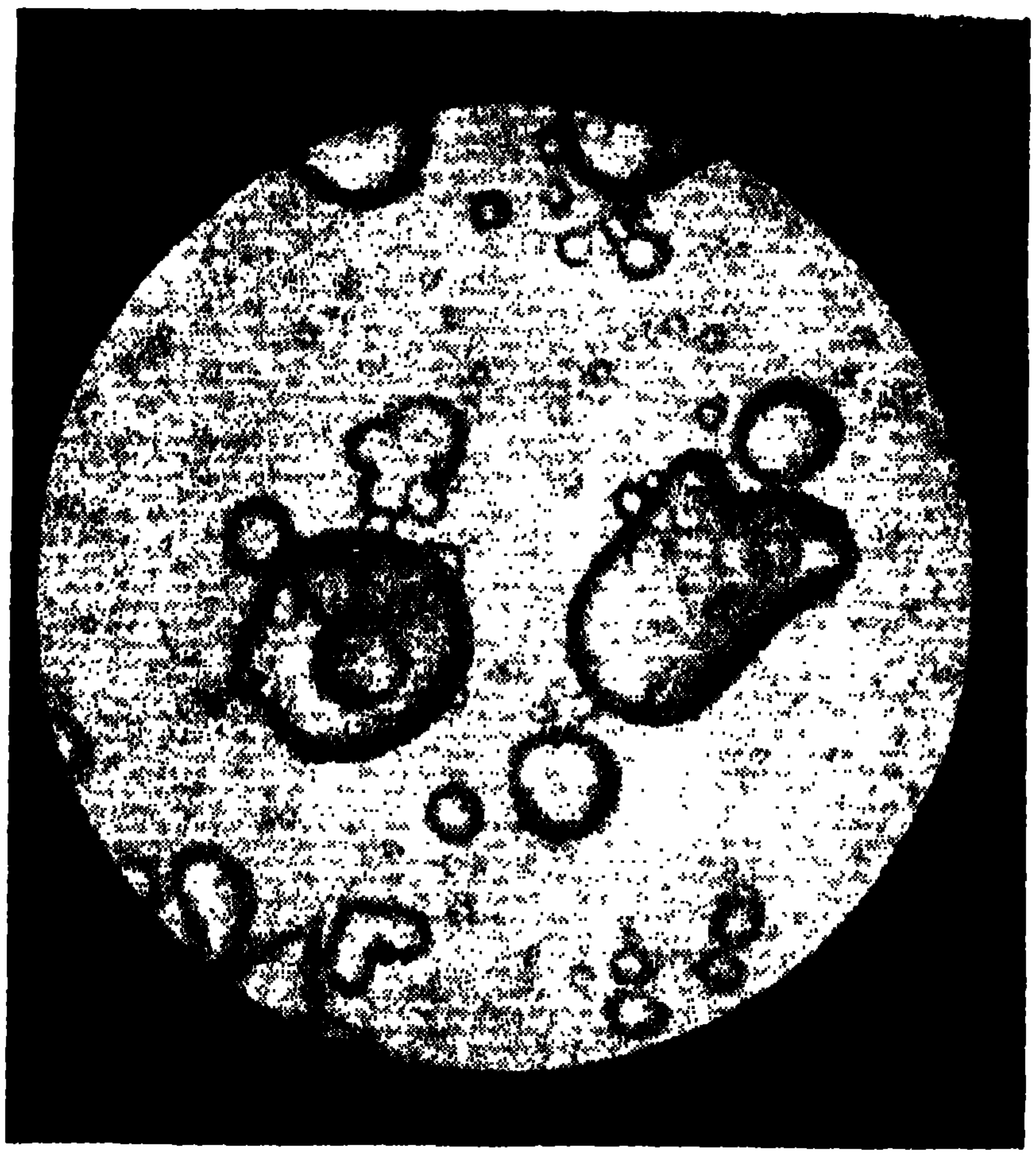

Fig. 7. Complex coacervate drops. In addition to protein they contain carbohydrate and nucleic acid (magnified 320 times)

Despite their liquid consistence the protein coacervate drops possess some sort of internal very elementary organization. They are characterized by a pronounced ability to adsorb different substances from the surrounding solution.

The adsorption is frequently complicated by the fact that the adsorbed substances begin to interact chemically with the substances of the drops proper, mainly with the proteins. Direct investigations show that on this basis processes of disintegration and synthesis of various substances are likely to occur in the drops.

In artificially produced coacervates these processes take place relatively slowly, but they may be accelerated by the inclusion of inorganic or organic catalysts in the drops. Thus, the general organization of the given coacervate, particularly its composition and structure, very strongly affects the correlation of the rate of the processes of disintegration and synthesis taking place in it. At the same time it is very important that the correlations of these rates are not immaterial to the subsequent fate of each individual coacervate drop we have produced. If by force of its definite composition and structure synthesis takes place more rapidly than disintegration under the given conditions of its external environment, the drop is a dynamically stable formation for the aforesaid conditions and may not only persist for an unlimited time, but even increase in size, grow. Conversely, the drop loses its stability and after existing for some time breaks up and disappears.

These properties, discovered by direct study of coacervate drops, artificially produced under laboratory conditions, bring us closer to understanding the new regularities which had to arise on the way to the formation of primary organisms.

In metabolism we are amazed by the extreme conformity between the organization of the living systems and their functions, the high coordination between the individual links of metabolism and its general tendency to preservation and self-reproduction of the whole system under the given conditions of the external environment. All this is really comparable with the expedience in the structure of the organs we directly observe in the higher organisms. But, both, here and there this expedience could have come into being only on the basis of similar regularities, i. e., on the basis of the interaction between the individual system and its environment, on the basis of Darwin's principle of natural selection.

Sooner or later the proteins or protein-like substances, which originated in the water of the Earth's primary hydrosphere, had to form complex coacervates. The properties of the coacervate drops, which were established when studied in the laboratory, show that the very formation of the drops had to lead with absolute necessity to the origination of a natural selection of these individual systems.

The coacervate drops, formed in the Earth's hydrosphere, were not submerged in ordinary water, but rather in a solution of different organic substances and inorganic salts. These substances and salts were adsorbed by the coacervate drops and later entered into chemical reaction with the substances of the coacervate itself. Processes of synthesis occurred and were paralleled by processes of disintegration. The speed of each of these processes depended on the internal organization of each given drop. The only drops that could exist for some time were those that possessed a certain dynamic stability, those in which under the given conditions of the external environment the synthetic processes were faster than the processes of decomposition. Otherwise the drops were doomed to disappear. The individual history of such drops ended abruptly and such "poorly organized" drops could, therefore, no longer play any part in the subsequent evolution of organic matter.

Conversely, the drops, in which synthesis prevailed over disintegration, were not only to survive, but even increase in size, grow. Hence, it was the drops with the most perfect organization from the point of view of their dynamic stability and rate of growth that constantly increased in size. But a drop cannot incessantly grow as a single whole. Upon reaching a certain size it divides forming "filial" drops. These separate parts were originally similar to the mother drop, but having separated each of them pursued its own course with its own changes, which either enhanced or diminished its chances for further existence under the given conditions of its environment.

Thus, parallel with the increase in the amount of organized substance and the growth of the number of coacervate drops in the hydrosphere of the Earth the quality of their organization also constantly changed. But as a result of the fact that this alteration constantly occurred under the strict control of natural selection it acquired a very definite direction. Any change in the organization of the drops, produced by the action of the external environment, was preserved for further evolution only if it satisfied the requirements for increasing the dynamic stability of the given coacervate and at the same time accelerated the processes taking place in the coacervate. In the beginning this acceleration was produced by a simple inclusion of some inorganic catalyst (for example, the salts of iron, copper, calcium, etc., widespread in nature) in the coacervate. Subsequently, by interacting with different substances, primarily with the proteins of the coacervate, these catalysts could greatly and specifically change their activity. As the coacervates grew, natural selection aided in the preservation only of the most perfect combinations of the complex catalysts-ferments, which most perfectly accelerated the reactions required for the creation of dynamic stability of the complex albuminous bodies, for the harmonious combination of the energic and synthetic reactions, and, consequently, for the constant self-renewal and self-preservation of the system under the given conditions of existence. In the end this led to the origin of protein bodies with an organized metabolism, i.e., to the origin of life on the Earth.

Could a similar process occur on other planets and what were the necessary conditions for it? These conditions were in large measure created as a result of the second of the above-mentioned stages in the development of organic matter. This was, in the first place, the existence of high molecular proteins or protein-like polymers capable of forming individual colloidal systems of the coacervate type. Secondly, the presence of water, the medium in which the coacervates could originate as a result of the unification of the protein particles previously present in the solution. This process could have occurred in large water masses (seas and oceans) or in any puddle, or even in the water that moistened the marls of the primary rocks.

The third requirement was the presence of a considerable amount of various organic compounds which could serve for a long time as the source of replenishing the substances composing the coacervates, because only on the basis of this replenishment could the coacervate drops grow and multiply. Without this there could be no selection and, consequently, no improvement of the drops. Only when this improvement had reached a very high level could the other, more complex systems of nourishing the primary organisms have arisen.

Fourthly, the water solution, where the coacervates formed and evolved, should have contained along with the organic substances also inorganic salts, compounds of the ash elements which are a necessary component part of all living bodies. The inorganic substances were necessary for the origin and evolution of coacervates because they created the requisite ionic concentrations and equilibria without which colloid-chemical phenomena are impossible. On the other hand, the inorganic substances acted as catalysts in the processes of synthesis and disintegration in the coacervate drops. The creation of the requisite mixture of inorganic compounds in the aqueous medium of a planet requires a complex and protracted process of migration of the elements composing these compounds.

Already in the process of the planet's formation there was a far-reaching selection of the elements of which the planet was made up. The compounds of these elements were subsequently forced to regular migrations on the surface of the planet in the region of its future biosphere where they mixed in various proportions and combinations. On the

Earth this occurred mainly on the basis of the water cycle, a process very efficient in this respect. But on other planets this could have come about in different ways. Besides, the correlations of elements characteristic of the Earth's biosphere were not absolutely necessary. Even under terrestrial conditions various organisms have different compositions of their ash elements both quantitatively and qualitatively. In addition, similar reactions in some living bodies are catalyzed by iron, in others by copper, and in still others by manganese or even vanadium. It goes without saying that on the different celestial bodies these processes may take place in ways very different and far removed from each other.

The period, during which the planet was being prepared, so to speak, for the formation of coacervate drops in its waters, was a very long one; to all appearance, it must have lasted many hundreds of millions of years. During that time, in the process of migration of elements, the inorganic composition of the biosphere had to form and the extraordinary complex chemical evolution of organic compounds from hydrocarbons and their simplest derivatives to proteins and other high-molecular compounds had to take place. But it also required an enormously long time for the simplest living beings to evolve from the primary coacervates in the process of their development as a result of slow natural selection. The duration of this third stage in the development of matter is quite comparable with the period which was required for the transformation of the simplest organisms into the modern higher plants and animals. During this period the environment, the external conditions altered repeatedly, though on the Earth they obtained within certain, rather narrow, limits approximating the present-day conditions. On other planets such changes in the external conditions could go beyond these limits without interrupting the organic evolution. It should be particularly emphasized that the decisive factor in the process of the origin of life was the interaction of the organic system with the external environment. The environment formed life. We can, therefore, have many different versions of the very idea of "life." It may involve a change in the nature of the protein structure, in the composition of the catalysts acting in the system, in the sequence of the metabolic reactions and, consequently, in the nature of the energic and synthetic processes arising on this basis, etc. It is only important that the constant self-restoration and self-reproduction of the system under the existing conditions of the external environment always be ensured.

It is, therefore, hard to believe that the forms of living beings inhabiting the other planets closely resemble the earthly plants and animals. Essential differences must have arisen at the very time life was in the making constantly increasing in the process of biological evolution.

The first organisms that came into being on the Earth had to be creatures capable of feeding only on ready-made organic substances. We get ample proof of this from the comparative study of the metabolism in all present-day organisms. The ability for precisely this type of feeding is peculiar to all known living beings without exception; it is inherent in the very organization of living matter. This type of feeding not only gave the primary living beings ready-made building material, but also made them independent of other sources of energy. They obtained all the energy they needed for life from disintegrating organic compounds, which had primarily originated abiogenically. And since there was no molecular oxygen in the terrestrial atmosphere at the time, the decomposition of the organic substances was effected by primitive organisms through fermentation on the basis of their anaerobic disintegration.

But as life developed the reserve of abiogenic organic substances on the surface of the Earth must have gradually become depleted. As we saw above the main mass of these substances came into being on our planet when it was at the reduction stage of its development before its transition to the oxidation stage. That period in the life of the Earth had passed. In the process of vital activities of the organisms the abiogenic organic substances on hand were gradually transformed into carbon dioxide while the new reserves of hydrocarbons arising from the interaction between carbides and water were replenished relatively slowly.

This radical change in the conditions of existence produced, at a definite period in the development of living nature, new forms of metabolism. Some organisms adapted themselves to the use of the energy formed by the oxidation of the reduced compounds of iron, sulphur and nitrogen. That is how chemosynthesis arose. But the living beings, which had acquired the ability of absorbing light of a definite wavelength and were thus able to use the energy of the light for the photolysis of water and for the synthesis of organic substances from the carbon of the carbon dioxide, made particular headway. The study of the essence of photosynthesis shows that this process requires a very perfect organization, a very efficient co-ordination of many light and dark reactions, the participation of a series of ferments and the presence of complex structural formations. Photosynthesis could have formed only when the organization of metabolism was on a rather high level.

The origination of photosynthesis radically altered the conditions of life on the Earth. The period of acute shortages of organic substances was past. Some of the organisms began to create the organic compounds they needed themselves, the others retained the previous forms of feeding utilizing the substances which now arose biogenically, in the process of photosynthesis. On this basis the organisms were divided into the world of plants and that of animals.

The origin of free gaseous oxygen, which had not formerly existed in the atmosphere of the Earth, was also a very important result of photosynthesis. This enabled most of the living beings considerably to rationalize their energy exchange by passing from anaerobiosis to oxygen respiration in which the energy hidden in organic substances is fully utilized. This transition was possible only because the former system of metabolism was augmented by new ferments and other protein substances. These additional systems can really be discovered in the protoplasm of higher organisms as certain super-structures on the former mechanism of anaerobiosis which is the basis of the energy exchange of all living beings. But since respiration came into being at a relatively late stage in the development of life these super-structures differ in the various representatives of the plant and animal worlds.

The changes in the structure (the morphology of living matter) were closely connected with those in metabolism. The cellular structure came into being; it was followed by the formation of multi-cellular living beings with their complex systems of tissues and organs, and, at last, by man.

We, certainly, cannot say how life originated and developed on other celestial bodies under the conditions peculiar to them. But it stands to reason that the organisms forming in the process of biological evolution must differ essentially from the terrestrial animals and plants since it is the environment that forms life.

Chapter II

POSITION OF THE SUN IN THE UNIVERSE

Of all the cosmic bodies the Sun, which is the central body of our planetary system and the closest star to us controlling the movements of the planets, is of the greatest importance to the Earth. Owing to its enormous mass the Sun not only unifies all the planets revolving around it into a single system, but also supplies them with an uninterrupted stream of radiation at the expense of the atomic energy spontaneously produced in its interior.

Without the emission of atomic energy the Sun could not have maintained its intensive radiation all through its existence, i.e., approximately over 4,000 million years. This becomes apparent if we only calculate the energy the Sun had to lose during the time indicated. Each second the Sun radiates 4×10^{33} ergs, while its mass equals 2×10^{33} grams. From this we can easily compute that each gram of the solar mass loses 2 ergs per second and that throughout its existence the Sun's energy outlay for each gram of its mass has constituted as many ergs as there are seconds in 8,000 million years (i.e., 2.5×10^{16} ergs). Despite this monstrous energy outlay the Sun is still a greatly heated body with a temperature of about 20 million degrees in its centre. Only "combustion" of hydrogen and its transformation into helium with a production of atomic energy can be the source of solar energy. Similar processes occur within each star. But they can take place only in bodies of a large enough mass. If a cosmic body has a small mass, as, for example, our Earth, atomic energy cannot be spontaneously generated because the temperature and pressure in the central parts of the body will be too low to overcome the inter-atomic forces and for the protons to penetrate into the nuclei.

Thus, the difference between a star and a planet is precisely in their masses. A body with a small mass is cold and there can be no nuclear reactions in it. But should the mass of a body increase approximately to 1/20-1/25 of the mass of our Sun its inner pressure and temperature will increase to the extent that nuclear reactions will be possible and this body will change into a star, i. e., it will spontaneously emit radiant energy.

Thus, the stars are luminous bodies because they produce atomic energy. That is why, when looking at the night sky, we get the impression that the Universe is composed chiefly of stars around which invisible planets may revolve. As a matter of fact the Universe has a much more complex structure. To start with, the stars are not haphazardly dispersed in infinite space, but form in it more or less vast systems. One of these systems, for instance, is our Galaxy—an enormous accumulation of stars which form on the firmament the familiar picture of the Milky Way.

In the centre of the Galaxy is its "nucleus," made up of numerous stars situated closer to each other than in the other regions of the Galaxy. The mass of the nucleus is very small compared with the mass of the entire Galaxy. Several spiral arms, in which especially bright and massive stars are located, as well as clouds of gaseous matter and minute dust matter absorbing a considerable part of the light emanating from the stars, issue from the nucleus. The observable division of the Milky Way into two wide branches, which later merge into a single band again, is only apparent. It depends on the absorption of light in the dust medium concentrated mainly in the equatorial plane of the Galaxy. The Galaxy is so large that it takes light, travelling at

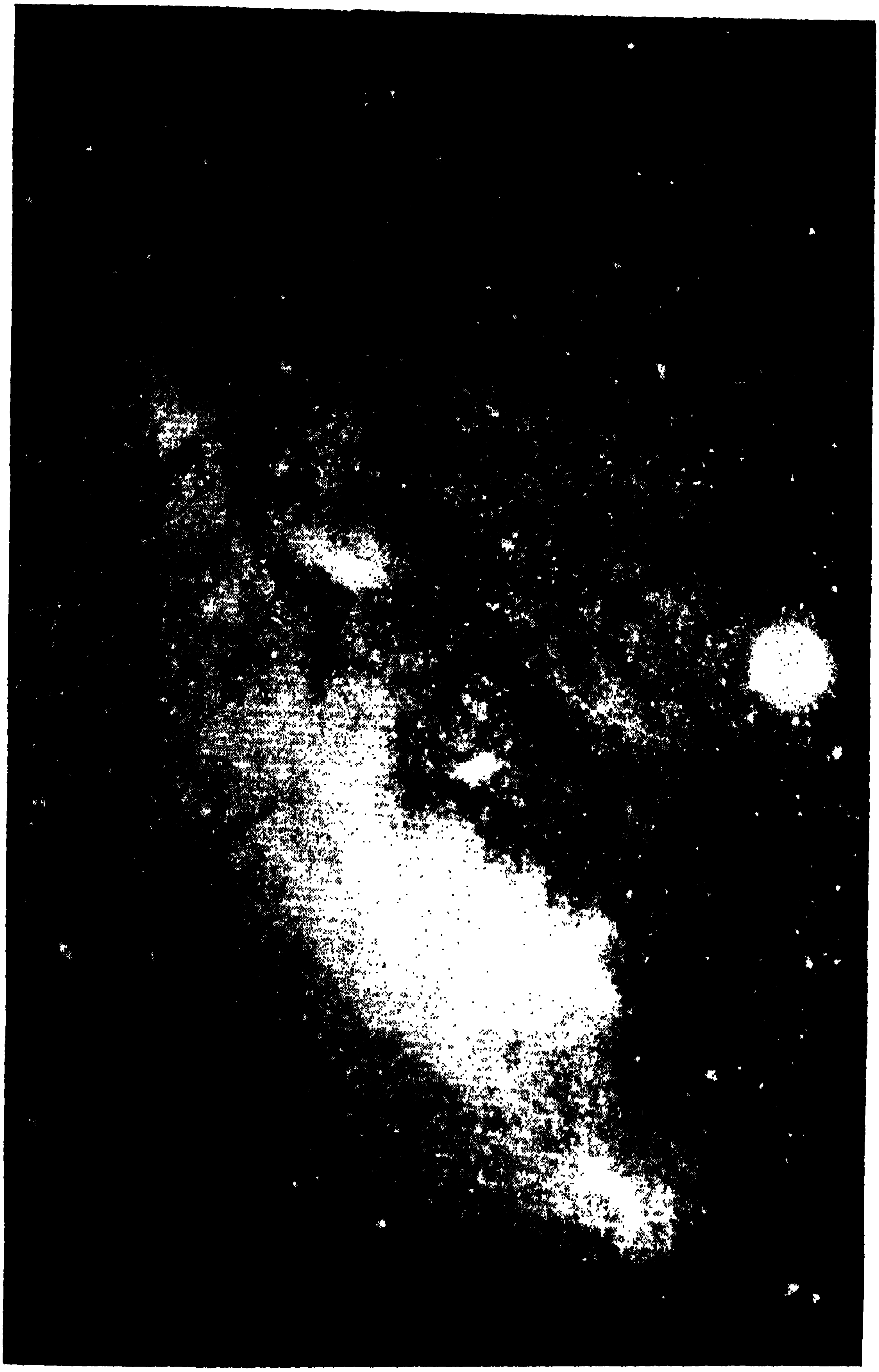

Fig. 8. Southern Milky Way over Alatau Mountains

a speed of 300,000 km/sec, close to 100,000 years to cross the Galaxy from one end to the other. For the sake of comparison let us note that light covers the distance between the Sun and the Earth (150 million kilometres) in only 8 minutes and 22 seconds.

Our Galaxy numbers about 150,000 million stars. The distance between them increases the further they are removed from the centre around which all stars slowly revolve. For example, our Sun, which is 30,000 light-years away from the Galactic centre, makes one full revolution around it in approximately 250 million years.

The time required by the Sun to make a full revolution around the Galactic centre has been accepted as a Galactic or cosmic year. On the basis of modern research the age of our Earth is set at 3,500-4,000 million years. It may be assumed that the entire planetary system is as old. The Earth is, consequently, about 15-16 cosmic years old; in other words, during the existence of the Earth and that of the other planets our Sun has already made 15-16 revolutions around the centre of the Galaxy.

Within our Galaxy the stars form closer groups; very frequently a group includes stars similar in their physical properties. In the first place we must mention the vast groups of stars, the so-called flat and spherical sub-systems, studied in detail by Soviet astronomers B. Kukarkin and P. Parenago mainly by the properties of the variable stars they contain. The flat sub-systems are arranged chiefly in the Galactic plane and consist of relatively slow-moving stars (the stars in the spherical sub-systems show a much greater variety of speeds). In addition, we know the so-called Galactic clusters of stars located mainly in the central region of the Galaxy, near its equator, and globular clusters made up of hundreds of thousands of stars and surrounding the Galaxy at a considerable distance from its centre. If you imagine yourself inside such a globular clusters you will find the entire sky covered with numerous stars which look very bright because of their relative proximity. In the globular clusters the stars move about a common centre of gravity along elliptic orbits with very long periods. No dust or gaseous inter-stellar matter is visible in these clusters while their stars have the same physical properties as those in the other regions of the Galaxy.

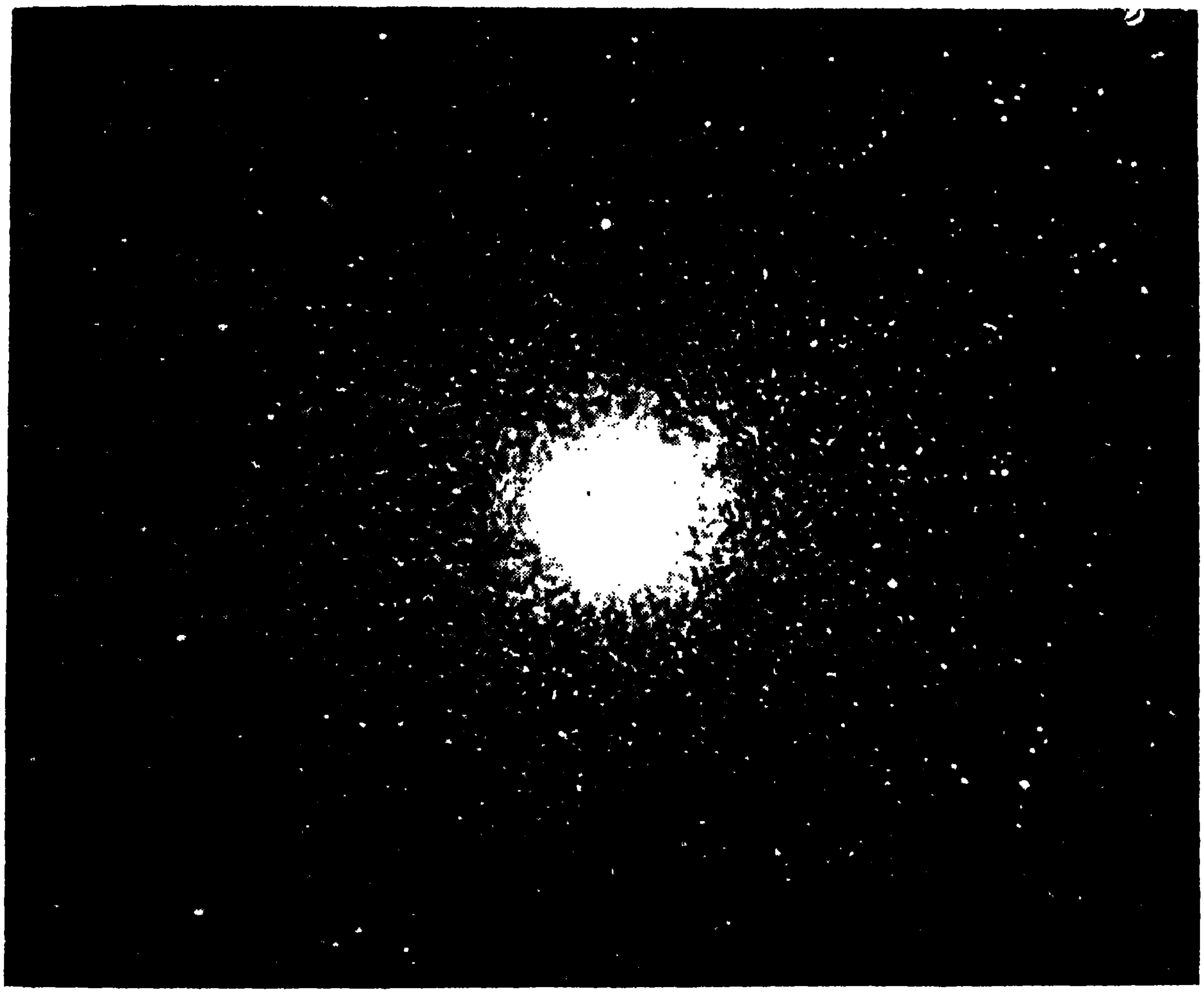

Fig. 9. Spherical accumulation

Of considerable interest from the point of view of the problem of life in the Universe are the close systems of double or multiple stars which, as a rule, revolve jointly around a common centre of gravity. The number of these systems is very large, but many of them are hardly distinguishable because they are too far from us and the stars composing them are too close to each other. Very many double stars cannot be distinguished in the telescope at all because the two stars composing them are too close to one another; their duality is discovered only in spectral observation because of the division of the spectral lines due to the unequal motion of the component stars along the line of sight; these are the so-called spectrascopic binaries. In some spectral-double systems the stars are so close to one another that in each of its revolutions the satellite eclipses the chief star and the brightness of the whole system alters for the terrestrial observer. These systems are known as eclipsing variable stars.

The study of the closest vicinity of the Sun, for example, the stars relatively not very far removed from it, namely, within the sphere with a radius exceeding the distance between the Sun and the Earth a million-fold (this constitutes about 16 light years) leads to very interesting inferences. Within this sphere there are 42 stars including the Sun. The nearest star to us, α Centauri located in the southern hemisphere of the firmament does not greatly exceed the Sun in brightness and is a double star. Sirius, the most brilliant, in its apparent brightness, star in the sky, is also one of the nearby stars. Sirius has a satellite which belongs to a special group of stars, the so-called white dwarfs, distinguished for their small size and enormous density. The mass of Sirius' satellite approximately equals that of the Sun, but its density is 30,000 times as great as that of the Sun. The other relatively bright star within the same sphere—the Procyon—is 6 times as bright as the Sun and is also a double system. Most of the remaining stars, located in the closest vicinity to the Sun, are much weaker than the Sun in actual brightness. They are mostly small red stars with a surface temperature of 2,000-3,000 degrees and their radiation is hundreds and even thousands of times as weak as that of the Sun. Nonetheless, many of them are double (11 double stars are known in the sphere of the indicated radius) and, perhaps, even more complex systems. Such are the stars 70 Ophiuchi, 61 Cygni, 60 Krüger and others. The 61 Cygni, which despite its proximity to us appears as a weak star of the 6th magnitude and is barely discernible with the naked eye, really consists of two stars nearly equal in brightness and close to one another. This star is also interesting because Holmberg and Strand have quite recently discovered a small invisible satellite near it. They happened to discover it by the small periodic deflections in the motion of the chief star which the satellite causes by its gravity. This invisible satellite was more fully studied by A. Deutsch in the Chief Astronomical Observatory at Pulkovo. A similar invisible satellite of the 70 Ophiuchi was discovered by Rayleigh and Holmberg. The masses of these satellites constitute only 2-3 per cent of the mass of the Sun and exceed the mass of Jupiter only 10-20-fold.

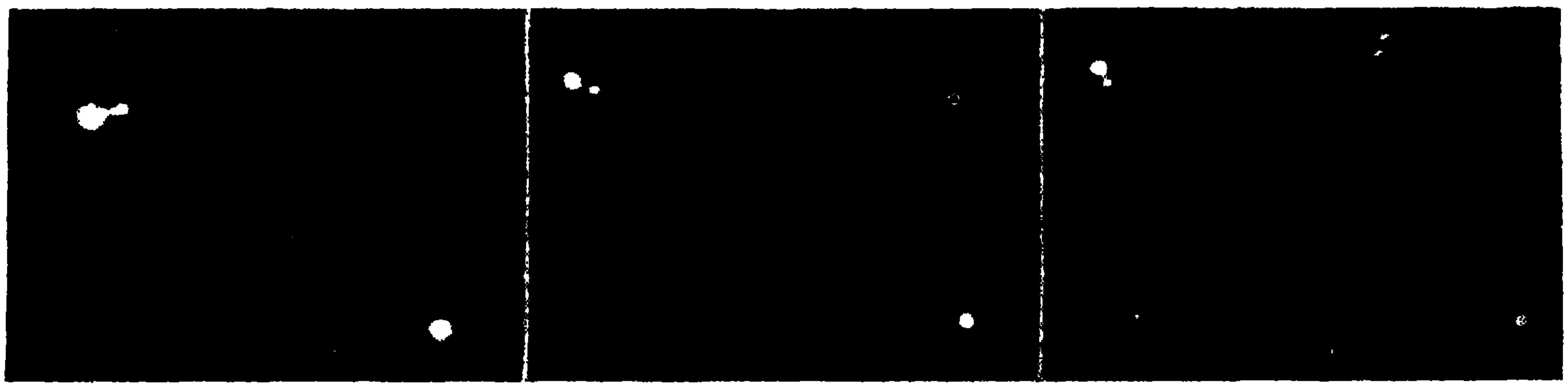
1908 *1915* *1920*

Fig. 10. Multiple star (orbital motion in the system of the double star Krüger 60, 1908-1920)

It should be noted, in accordance with B. Kukarkin's remark, that if there are really two planets of such dimensions as Jupiter and Saturn in the system of 61 Cygni their joint action could produce the same effect as that of one more massive body. At any rate such a satellite cannot be an ordinary star because with its insignificant mass the temperature of its surface could under no circumstances exceed several hundred degrees which is not enough for its own luminescence. Guided by purely physical considerations we can also prove that such small bodies cannot contain sources of nuclear energy, i.e., cannot be stars, because otherwise they would simply have to disperse in space.

As G. Idlis has shown, the smallest mass of a star still in a stable state must be larger than 0.04-0.05 of the mass of the Sun.

Thus, by studying the stars in the closest proximity of the Sun and by considering them typical representatives on the stellar population of our whole Galaxy we come to very important conclusions. Firstly, most of the stars form close double or multiple systems and, secondly, as can be expected with a considerable degree of probability, small dark bodies, which are real planets and which can shine weakly only by receiving light from their suns, revolve around many stars. It goes without saying that the discovery of these small bodies is connected with great difficulties, and only the most massive planets of even the nearest stars can be discovered by modern astronomical means. It may be pointed out that Jupiter, the largest planet of the solar system, has 1,047 times as small a mass as the Sun and the periodic gravitational deflection of the Sun produced by its gravity could, therefore, have been in no way discovered by the modern means of research even from the star nearest to us. It would be impossible to see Jupiter through the most powerful up-to-date telescopes because even from the α Centauri it would appear as a celestial body of the 26th stellar magnitude, i.e., several hundred times as weak as the weakest stars accessible to the most powerful modern instruments. Besides, being at so close an angular distance from the Sun, Jupiter would be lost in its rays. But the fact that planets, though much more massive than those in our solar system, have been discovered with the nearest stars despite all these difficulties leads to the conclusion that, generally, very many stars in the Universe have planetary systems.

The conclusion that double and multiple stars are very widespread in the Galaxy finds confirmation in G. Kuiper's recent detailed study. On the basis of all factual data on the visual and spectroscopic binaries now on hand Kuiper inferred that the minimum number of double and multiple stars in our Galaxy constitutes at least 80 per cent of all the stars in the Galaxy. This means that of every 10 stars taken at random eight form part of a double or multiple system. In addition, a triple star is counted as two double stars, a quadruple—as three double stars. Furthermore, Kuiper finds that the mass and brightness of the satellite in the double star system do not essentially depend on the mass and brightness of the main component; hence, the mass and brightness of the component stars in the double-star systems must be considered absolutely independently for each of them. It must, therefore, be concluded that double stars cannot, as a rule, originate as a result of the division of one formerly existing star with a great angular momentum. This conclusion is also warranted by the fact that in case of the division of one star into two components the distance between them could never exceed several dozen astronomical units (i.e., distances between the Sun and the Earth). Only the closest pairs, in which the components nearly touch, could have formed by such division, but not everything can be explained even in this case. Already Jeans demonstrated theoretically that the division of one star into two components is impossible if this star has a heterogeneous structure. In addition, it follows from Kuiper's study that both the visual, i.e., double stars with great distances between the components, and the spectral-double, i.e., close stellar pairs, essentially form one class of celestial objects and, therefore, both are of the same origin.

The conclusion that the stars form, as a rule, more or less close pairs and that only very few of them are single stars, like our Sun, is of great importance to the consideration of the problem of life in the Universe. The fact is that planets can have simple, close to circular, orbits only when there is a single centre of gravity, i.e., in a single-star system. The planets in a double, or even more complex system of close stars, must describe highly complicated curves around some common centre of gravity. This sharply differs from the situation in our solar system. The Earth and the other large planets revolve about the Sun in almost circular orbits, which ensures them a more or less constant source of solar radiation on their surface. But if the Sun were a double system, the planetary orbits would be so complicated and the distances between the planets and the Sun could change so considerably that sharp fluctuations in the radiation reaching the surface of the planets would be inevitable. E. Strömgren and his associates have computed numerous very complex trajectories of planets of a stellar pair in which the mass of one star is ten times that of the other star, while the planet revolving in this system has an absolutely insignificant mass and its gravity cannot affect the mutual motions of the stars. It is, thus, obvious that for life to be possible on planets it is extraordinarily important that these planets be connected with a single and, by no means, with a multiple star.

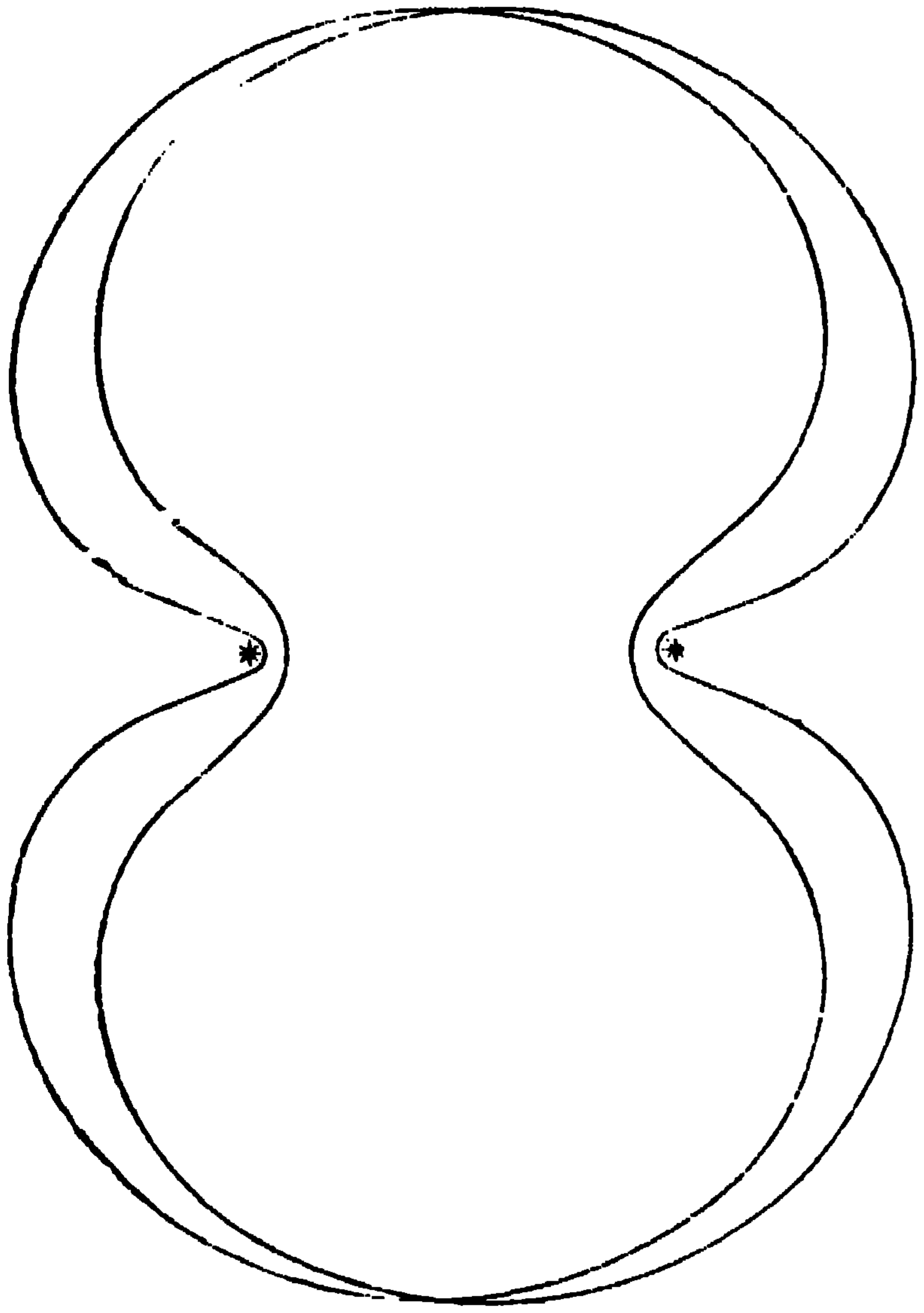

Fig. 11. Possible orbit of asteroid in relation to two centres of gravity

It has already been pointed out that the ability to emit atomic energy is a characteristic property of every star. The atomic reactions, which take place in the stars and are connected with the penetration of protons into the nuclei of the heavier elements, depend to a great extent on the temperature in the centre of the given star, i.e., on the energy of the motion of the atoms of gas. But the central temperature of gaseous spheres in equilibrium is proportional to the mass and inversely proportional to the radius. It is, therefore, inevitable that the more massive stars emit more energy per unit of mass. With the increase in the mass of a star the amount of energy produced per gram of substance sharply increases. If, for example, a star has a mass ten times that of the Sun, its radiation is, on the whole, 10,000 times that of the Sun. The massive stars also have a higher surface temperature, which runs into many thousands of degrees. There are quite many of these stars, for example, in the constellation of Orion and in some other regions of the sky. The radiation of these stars is so great that even the transformation of hydrogen into helium in their interiors cannot extend their existence to thousands of millions of years. Such massive stars can exist only millions, but not thousands of millions of years. Some of them could have come into being only several hundred thousand years ago and, thus, from the cosmic point of view are very recent formations.

Only relatively small stars, like our Sun, with moderate radiation can exist long without a substantial loss of mass. This is of tremendous importance to the origin and evolution of life on the planets revolving around such stars.

At the same time it must be remembered that there is a considerable category of stars in an unstable state which is manifest in the changes in their sizes, as well as in temperature and radiation.[1] If our Sun were a physically variable star and the intensity of its radiation changed by at least 50 per cent in either direction from its mean the temperature on the Earth's surface would constantly fluctuate within

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[1] All stars, whose apparent brightness changes, are called variable in the broad sense of the term. Not in all of these stars is the change in brightness connected with a real increase or decrease in their brightness. There are so-called eclipsing variable stars. These are close stellar pairs in which the satellite, revolving about the chief star, periodically eclipses it. This causes a change in the apparent brightness, though there is, certainly, no real change in the brightness (amount of energy radiated).

The stars, whose brightness changes periodically or non-periodically by force of internal physical causes, are called physically variable stars. The Cepheids form a special class of these stars. The brightness of each Cepheid star changes strictly periodically, but these periods differ with different Cepheids (from a few hours to many weeks). In

60°C, which would hinder the development of life. The so-called novae belong to a special type of variable stars.[1] For some reasons, not quite clear as yet, the brightness of such a star suddenly increases nearly 100,000-fold in a few hours, its entire outer shell begins stormily to expand and be ejected into space as a result of an internal explosion, enveloping the blazing star in a vast cloud of rarefied gas. These phenomena are observed in our Galaxy several times a year. Flashes of much shorter duration and of lesser significance are also sometimes observed in dwarf stars surrounded by a vast gaseous shell, when the general brightness of the star increases 10-20-fold within a few hours. These are, however, rather rare phenomena in our Galaxy.

Of much greater importance is the fact that along with its regular radiation, which is propagated in the form of streams of light and heat, each star produces streams of corpuscles, i.e., it also possesses corpuscular radiation and, consequently, constantly loses in mass in the process of its development. This conclusion grows out with mathematical necessity from the comparison of the principal regularities in the structure of stars, established by modern astrophysics, and is also confirmed, as A. Masevich's painstaking calculations have shown, by the theory of the internal structure of stars.

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size and brightness all Cepheids are giant and super-giant stars, but it has long since been established that the longer the period of change in the brightness of a Cepheid the greater its brightness.

According to modern views the fluctuations in the brightness of the Cepheids are produced by periodical pulsations of these stars due to internal physical causes. In these cases the size and brightness of the star change. (*Editor's note.*)

[1] At one time it was believed that in their evolution all stars must flare up as novae. It followed that the Sun would also have to flare up in time. The study of the physical nature of stars has shown the erroneousness of this assumption. Only stars of a certain type can flare up as novae and these flare-ups can recur periodically. The Sun does not belong to this type. It is a stable star and its physical state is not subject to any considerable changes. This stable state of the Sun will, undoubtedly, last for many more thousands of millions of years. (*Editor's note.*)

In massive stars the constant ejection of mass and, especially, separate explosions, can be observed directly. Academician G. Shain has demonstrated that some giant stars are in an unstable state though no intensive explosions occur in them. Their external shell is almost completely retained by forces of repulsion, which are probably of an electromagnetic nature, and is, therefore, as it were, weightless. These stars constantly lose substance which goes into interstellar space.

Corpuscular radiation, i.e., the outflow of the star's substance into its environment, is particularly easily observed when the star has a close satellite, as is the case with the spectroscopic binaries. Very well known is the β Lyrae spectroscopic binary with its close satellite, which partly eclipses the chief star during each revolution. An analysis of the change in the β Lyrae's spectrum has shown that the chief star constantly emits a powerful stream of gas which partly envelops the satellite and partly enters the common gas ring surrounding the whole system. Analogous phenomena have been discovered in all massive spectroscopic binaries. All of them, as observations show, intensively lose their substance by emitting it into the inter-stellar space. This phenomenon is at least partly due to the fact that the massive stars, as a rule, rotate very rapidly around their axes. The rate of rotation at the equator frequently reaches 300, 400 and even 500 kilometers per second. The fast rotation, during which a considerable centrifugal force is developed, causes the emission of substance chiefly at the equator of the star, and the emitted substance arranges itself mainly in the plane of the equator, as it is in many cases observed.

It may be thought that corpuscular radiation is a general natural phenomenon, but it occurs very vigorously in all massive and hot stars and much less vigorously in the weaker stars. For example, this phenomenon is uncommonly weak in the Sun, which has long since reached a stable state and has hardly changed its mass in the last one thousand million years. In addition, it has been established that corpuscular radiation is, generally speaking, proportional to

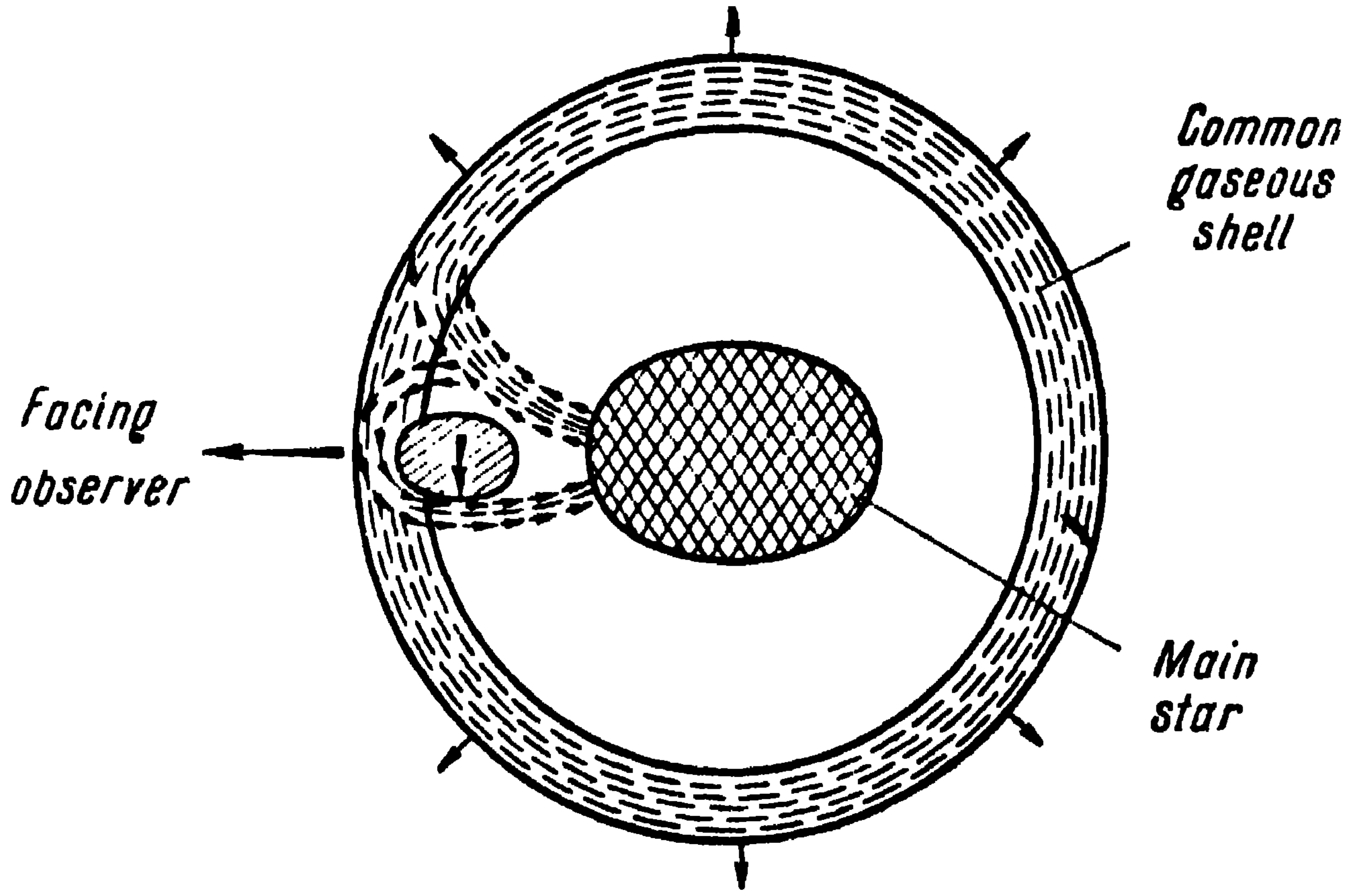

Fig. 12. Diagram of matter emission in the system of β Lyrae

ordinary light-radiation. On this basis we can picture purely theoretically the distribution of stars according to their luminosity, masses and temperatures, which is actually observed and is known as the luminosity-temperature diagram establishing a relationship between the spectra of stars and their luminosity.

This diagram has been considerably supplemented in recent years by P. Parenago and B. Vorontsov-Velyaminov. Most of the stars in our Galaxy are arranged in this diagram in a definite row known as the main sequence. It includes the more massive and, consequently, brighter stars which also have a higher temperature and very high rate of rotation around their axes. The smaller the mass, the lesser the luminosity, the lower the temperature and the slower the rotation. This is particularly well seen in the investigation of stars belonging to the same cluster in which all stars are, practically, equidistant from us. The stellar clusters of the Pleiades, Hyades, Praesepe, etc., are a good example of this.

The correlations between the physical properties of stars can be explained theoretically on the basis of the phenomenon of corpuscular radiation. It appears that in the process of its development each star must necessarily move along the curve of the main sequence in the direction of smaller mass and slower rotation. This slowing down in rotation, which occurs in the course of stellar evolution, is due to the fact that by corpuscular radiation the star along with its matter also loses part of its angular momentum and its rotation is, consequently, slowed down.

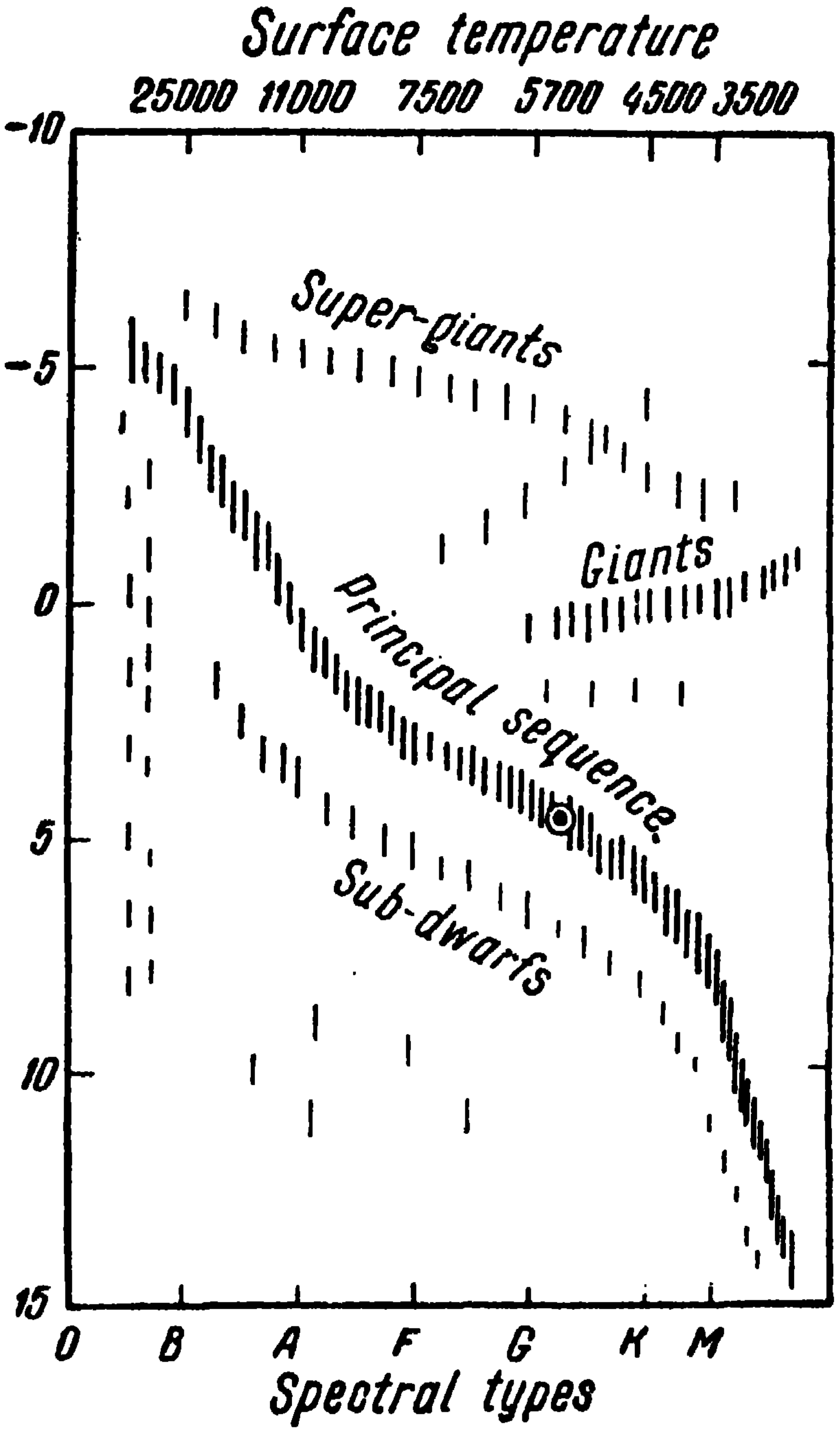

Fig. 13. Brightness-temperature diagram

It should be noted that at its origin a star must not necessarily have a big mass. On the contrary, as the study of separate Galactic clusters shows, for example, the cluster of the Pleiades, where for several bright and hot stars there are a few hundred weaker ones, stars may have different masses from the very outset. Nevertheless, the further evolution of the star always proceeds in the direction of smaller mass and lower temperature.

If we consider the history of the development of our Sun, which is a very old star, in the light of these ideas we may come to the conclusion that it was formed several thousand million years ago, that it originally had a mass several times as large as that of today and that it rotated very fast. We may assume that the planets were formed at about the same time as the Sun and that they are approximately as old, their age being several thousand million years. The evolution of the Sun should, at the same time, have condi-

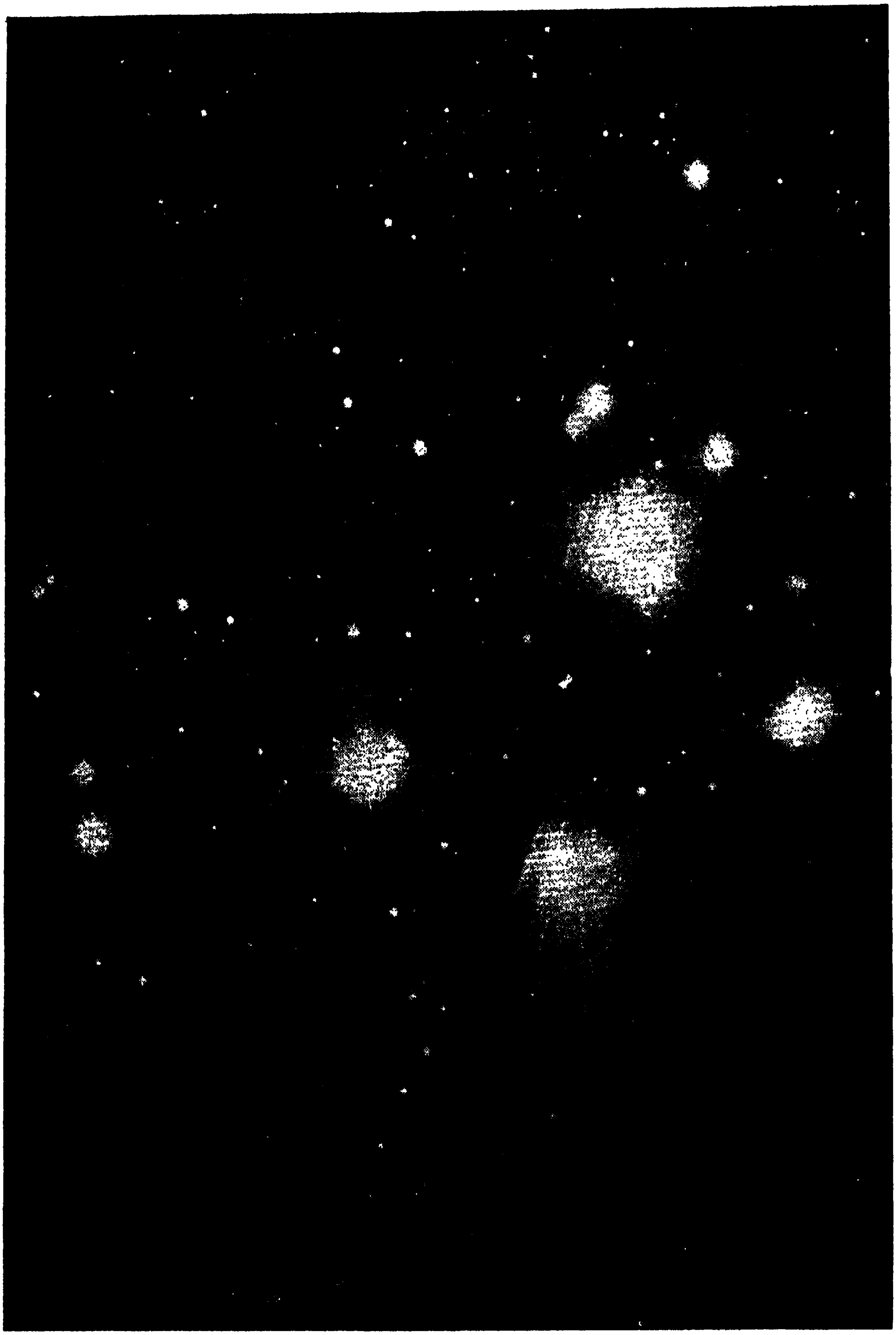

Fig. 14. Stellar accumulation of the Pleiades surrounded by a dust nebula.

tioned the evolution of the planetary system as a whole. As a matter of fact as the solar mass diminishes the force with which the Sun attracts the planets also diminishes. Besides, as Jeans has shown, the product of the mass of the Sun by the radius of the planet's orbit must remain constant; in other words, in times long past the linear dimensions of the solar system were as much smaller as the mass of the Sun was larger. This fact is also of great importance in the study of the conditions of life on the planets during the long period of their evolution. For our solar system, however, this change in the last one thousand million years of its existence has been absolutely insignificant, since the mass of the Sun has suffered very little change during this time.

However, for the more massive stars, whose masses change much faster, the sizes of the orbits of their possible planets are far from constant. At the same time the thermal conditions on the planets themselves must change to a much greater extent.

As a matter of fact, the change in mass is paralleled by a change in the total stream of radiant energy Q, emitted by the star and is proportionate to the fourth power of its mass. The amount of energy E that falls on a unit of the planet's surface also changes in inverse proportion to the square of its distance from the star.

Thus

$$E \sim \frac{Q}{r^2}.$$

But, since according to the aforesaid

$$Q \sim M^4, \quad r \sim M^{-1},$$

we get that the extent to which the planet is heated by its central body, the star, is at each given moment proportional to the mass of the star raised to the sixth power. But the temperature of the planet's surface under conditions of thermal equilibrium will be proportional to the mass of the star raised to the $^3/_2$ power.

$$T \sim M^{3/2}.$$

If, for example, the mass of the star changed by only 20 per cent the mean temperature of the planet would have to change by nearly 30 per cent. If our Earth were under these conditions its mean temperature, which equals approximately 290° abs, would drop to 203° abs, i.e., instead of +17°C it would become —70°C.

This change in temperature would have been unfavourable to the development of life on the Earth, and this influence would have made itself felt in the slightest change in the mass of the Sun. It, therefore, follows that the existence and development of life on any planet for a long time is possible only if the planet has been revolving about a star which has been in a stable state for thousands of millions of years. The Sun is precisely such a star, but most of the bright, hot and massive stars have come into being recently and they cannot, apparently, have planets where there could be life.

As we have already mentioned our Galaxy with its extension of approximately 100,000 light years has close to 150,000 million stars. This number of stars in the Galaxy seems extraordinarily large, but it is really very small as compared with the volume of the Galaxy. The distances between the stars are enormous, but the sizes of the stars are insignificant in comparison with these distances. This is the characteristic feature of our stellar system. Thus, for example, the diameter of the Sun is about 200 times as small as the diameter of the terrestrial orbit[1] and 7,600 times as

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[1] The amplitude of the star sizes is very big. At the same time the amplitude of the stellar masses is not so significant. Some stars (ε Aurigae, VV Cephei) are larger than the Sun thousands of times in diameter and thousands of millions of times in volume. But the mass of such stars is only several dozen times as great as that of the Sun. Their substance is extraordinarily rare—its density is thousands and sometimes millions of times as low as that of the earthly atmosphere.

The so-called white dwarfs are the exact antithesis of the supergiant stars. Their sizes are comparable with those of the planets in the solar system. Sirius' satelite, for example, is smaller than Uranus small as the diameter of the orbit of the farthest planet in the solar system (Pluto), but at the same time the diameter of the Sun is 52 million times as small as the distance from us to the nearest α Centauri star. There are stars which exceed the Sun hundreds and even thousands of times (and in volume even millions and thousands of millions of times) in linear dimensions, but even their sizes are negligible compared with the inter-stellar distances. That is why even with the most chaotic distribution of the stellar velocities the probability that some star may pass very close to our Sun or, at least, accidentally go through our planetary system is extremely small. According to Jeans' calculations, with the present structure of our Galaxy the passage of any star close to our Sun may be expected only once in 10^{17} years. Since our Galaxy, as well as our Sun, is approximately 10^9 years old this may occur only with one star out of 100 million throughout the existence of the Galaxy.

About fifty years ago the famous scientist Henri Poincaré deemed it possible to compare our Galaxy with a cloud of rarefied gas in which individual molecules play the part of stars. In an ordinary cloud of gas the relationships between the molecules are determined by the laws of gas dynamics and, in the first place, by the law of equal distribution of the kinetic energies among the molecules of different masses. But our Galaxy is built differently. The action of irregular forces on the stars is negligibly small because the stars hardly ever come close to each other. Thus, the-real structure of the Galaxy does not even approximately correspond to the state of equilibrium in which Maxwell's law of distribution of velocities works. We may, therefore, be sure that once the planetary system has formed it will not suffer the catastrophe of a close passage of an extraneous star which may

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and Neptune, while some white dwarfs are smaller than the Earth. But the mass of the white dwarfs corresponds to that of the Sun. Their substance is sometimes tens of thousands of times as dense as the heaviest elements on the Earth. (*Editor's note.*)

sharply change the planetary orbits or even fully sever them from the Sun.

In his book *La fin du monde* C. Flammarion discusses the problem of the possible causes of cessation of life on the Earth in the future. He speaks of the possible meeting of the Earth with a comet, of the cooling of the Sun and of the Sun's collision with another star.

None of these assumptions have any basis in fact. The Earth has met with comets and has even gone through their tails with no ill after-effect many times in its history. The Sun cannot grow cold because its radiation is supported by nuclear reactions—transformation of hydrogen into helium. Because of the abundance of hydrogen in the Sun and the insignificance of the Sun's radiation these reactions will continue many more thousands of millions of years. Last but not least, as has just been pointed out, not only a collision, but even a close meeting with another star is actually impossible. However, our planetary system, like those of other stars, must have repeatedly gone through rarefied gas and dust clouds frequently encountered in the inter-stellar space.

In 1904, Hartmann discovered in the spectra of the hot stars, so-called, stationary lines belonging to ionized calcium. According to their nature these stars cannot be characterized by such lines; besides, it was established that the newly discovered lines did not move with the motion of the stars along the line of sight determined according to Doppler's effect. It was, thus, laid down that these lines belonged to inter-stellar gas rather than to stars. A detailed study of the inter-stellar environment has shown that it abounds, primarily, in hydrogen, which is the most widespread element in the Universe, though it is rather hard to discover. In the vicinity of our Sun there is an average of 2-3 atoms of hydrogen for every cubic centimetre of inter-stellar space. Helium, another gas widespread in nature, is present in only one-tenth this amount. The other elements are represented in even lesser quantities. All in all, for every thousand atoms of hydrogen in the inter-stellar environment there are approximately 100 atoms of helium, 10 atoms of oxygen, carbon, nitrogen and neon taken together, 2-3 atoms of iron, potassium, calcium, silicium, magnesium, and other elements. Such are the quantitative proportions of the various elements in the Universe. As the analyses of the chemical composition of the stellar atmospheres and planetary nebulae have shown the same proportions obtain there, too.

Thus, the density of the substance in the Universe is determined, primarily, by hydrogen which is the most widespread element, quantitatively greatly exceeding all the other elements taken together despite the fact that throughout the existence of the Galaxy there has been a constant and irreversible process of formation of very stable atoms of helium at the expense of the diminishing number of atoms of hydrogen.

In connection with this we should mention the following interesting circumstance. A normally formed cosmic body with a sufficient mass and composed of various elements in the above-mentioned proportions at a temperature suitable for the existence of life must be made up nearly exclusively of gaseous substance. The chemical elements, which at the temperature required for organic life are in a solid state and can form the surface of the planet, are contained only as insignificant admixtures. This aspect of the question will later be treated in greater detail.

The inter-stellar substance in the gas and dust nebulae is noted for its absolutely insignificant density; thus in the vicinity of our Sun it constitutes approximately $3x10^{-24}$ gm/cm^3, i.e., one gram of substance per volume of 300 million cubic kilometres. However, the total mass of this substance in the volume of the entire Galaxy is approximately of the same order as the total mass of all the stars. It should be remembered that inter-stellar matter is distributed in the Galaxy extremely unevenly. The intensive turbulent motions, which result from considerable velocities, create great "overtalls" of densities. At any rate, direct observations show that in the Galaxy there is a large number of diffuse gas clouds separated by considerable intervals. According to the approximate estimates of V. Ambartsumyan, S. Gordeladze and P. Parenago there is one such nebula per volume of a cube with a rib of about 2 million radii of the Earth's orbit (close to 32 light years). Very often, as Academician G. Shain and his associates have shown, the mass of such a nebula is many times as great as that of the Sun. Stars are frequently observed in these nebulae which have either formed from the substance of the nebulae or are of the same origin with them. Particularly interesting is the well-known Nebula of Orion almost visible with the naked eye. The mass of the entire substance connected with this nebula in the form of gas, dust and, perhaps, some bodies of pre-stellar nature constitutes at least one million solar masses and by far exceeds the mass of stellar cluster which centers with this nebula and largely consists of stars, apparently, recently originated from the same environment.

Though the mechanism of star formation is not as yet fully known, in a number of cases it can hardly be doubted that the stars must form from an originally diffuse medium with an admixture of solid particles of dust playing an important part. As a matter of fact, the dust particles, whose temperature should be much lower than that of the surrounding gaseous environment, serve as a powerful means of cooling the nebula; besides, owing to their extensive absorbability they screen the nebula from the heat of the neighbouring stars. This aids in the condensation of the nebula with the subsequent development of ordinary stars from these condensations.

Due to the great volume of the gas and dust nebulae the stars, including our Sun, moving in the Galaxy, may repeatedly enter the nebulous medium. The question is: what can we expect in such cases?

Some foreign scientists, as, for example, Hoyle, Bondi, Lyttleton and McCrie studied whether it was possible for a passing star to seize substance from the surrounding nebula and whether the star could considerably increase its mass and acquire additional hydrogen and other elements.

Fig. 15. Nebula "America"

It was supposed that under those circumstances the star could become "rejuvenated," as it were, and that it should move up along the curve of the main sequence on the spectra-luminosity diagram. The aforesaid scientists have come to the conclusion that this process may occur only if the star has a large mass and approaches the nebula very slowly. To all intents and purposes, however, this phenomenon may be considered absolutely impossible. As has been shown by G. Gurzadyan, each sufficiently actinic star repels on its way the atoms of hydrogen by its radiation; V. Safronov has found that all stars with a surface temperature of about 8,000°C and higher repel fine dust with greater force than they attract it. This was also confirmed by various observations on which we do not have to dwell here. Generally speaking, no direct encounter of a star with separate molecules or particles of a nebula could be of any significance even if this did actually occur.

That is why even the scientists who propound the possibility of star "rejuvenation" believe that this can occur only indirectly: by its gravity a star distorts the paths of passing particles and makes them condense in its rear part whence these particles colliding with each other and losing their kinetic energy finally fall on the star.

But even this explanation would fit in the case of the dust particles capable of inelastic collisions with a loss of kinetic energy only if the star penetrated the nebula sufficiently slowly. But any outside star originally unconnected with a nebula must inevitably gather speed because of the gravity of the nebula. Similarly any particle falling on the Earth must reach the Earth at the rate of at least 11.3 km/sec, which is its speed created by the gravity of the Earth; at the same time any body on the Earth must gain a velocity of at least 11.3 km/sec in order to leave the Earth and go into inter-planetary space.

If the star moves at a very slow rate with respect to the nebula it must be genetically connected with it. In this case the star most probably developed in the bosom of the nebula and did not find itself in it as a result of accidental passing.

On the other hand, the question is: during the passage of our Sun or some other star surrounded by a family of planets through a nebula can the radiation falling on the surface of the planets noticeably weaken because the light of

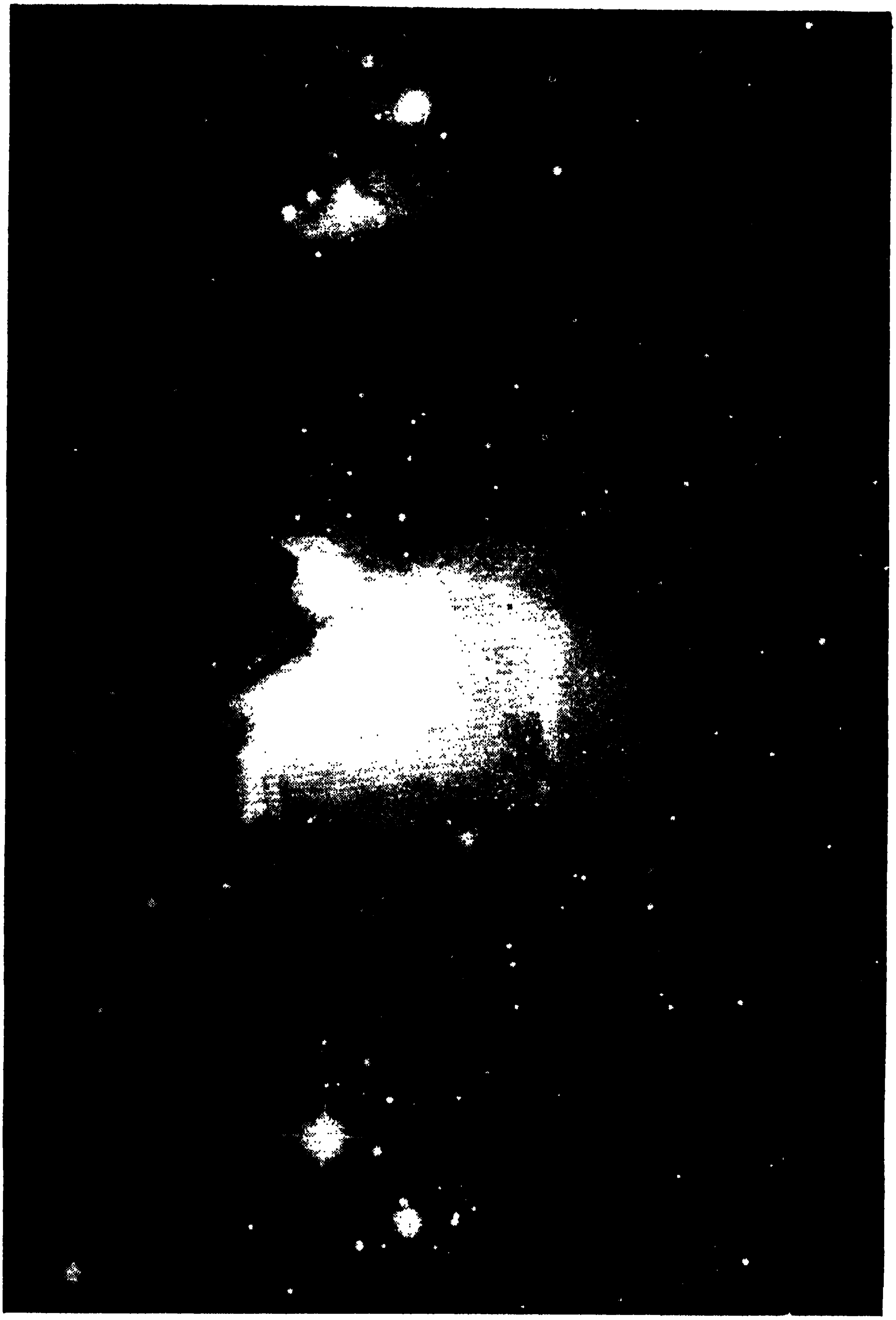

Fig. 16. Nebula in Orion

the star is absorbed by the nebula? Such weakened radiation may result in a change of the living conditions on the planets. Some scientists connected the glacial periods in the history of the Earth with such accidental passages of the Sun through dense cosmic clouds.

It should be mentioned that, though no systematic change in the intensity of solar radiation can be established during the past geological epochs, the temperature on the surface of the Earth changed many a time. Thus, for example, according to Brooks, glaciation in the past occurred on the Earth during the Cambrian period (about 400 million years ago), then at the very end of the Carboniferous and during the Permian periods and, finally, during the Pliocene and, especially, the Pleistocene epochs. On the other hand, the end of the Permian period, the Cretaceous period, the beginning of the Mocene and the Miocene were noted for their moderate climates. During the Silurian and Devonian periods and during the greater part of the Carboniferous, as well as the Triassic and Jurassic periods, and later during the Eocene and Oligocene the Earth had a warm climate.

Thus, in the last 400 million years of the Earth's history its climate changed quite sharply and without any regular periodicity. But a simple calculation shows that these changes in the climate could not have resulted from the passage of the Sun through cosmic clouds, since direct absorption inside the inter-stellar cloud all along the radius of the Earth's orbit is too insignificant. Besides, the appearance of the glacial period is connected primarily with the sharp increase in the condensation of moisture in the Earth's atmosphere and its precipitation in the form of rain and snow. On Mars, for example, there is no glacial period simply because there is too little water and there is nothing to freeze though the temperature of this planet is much lower than that of the Earth.

Considering that the periods of glaciation on the Earth coincided with those of intense mountain formation and general tectonic faults always connected with a sharp intensi-

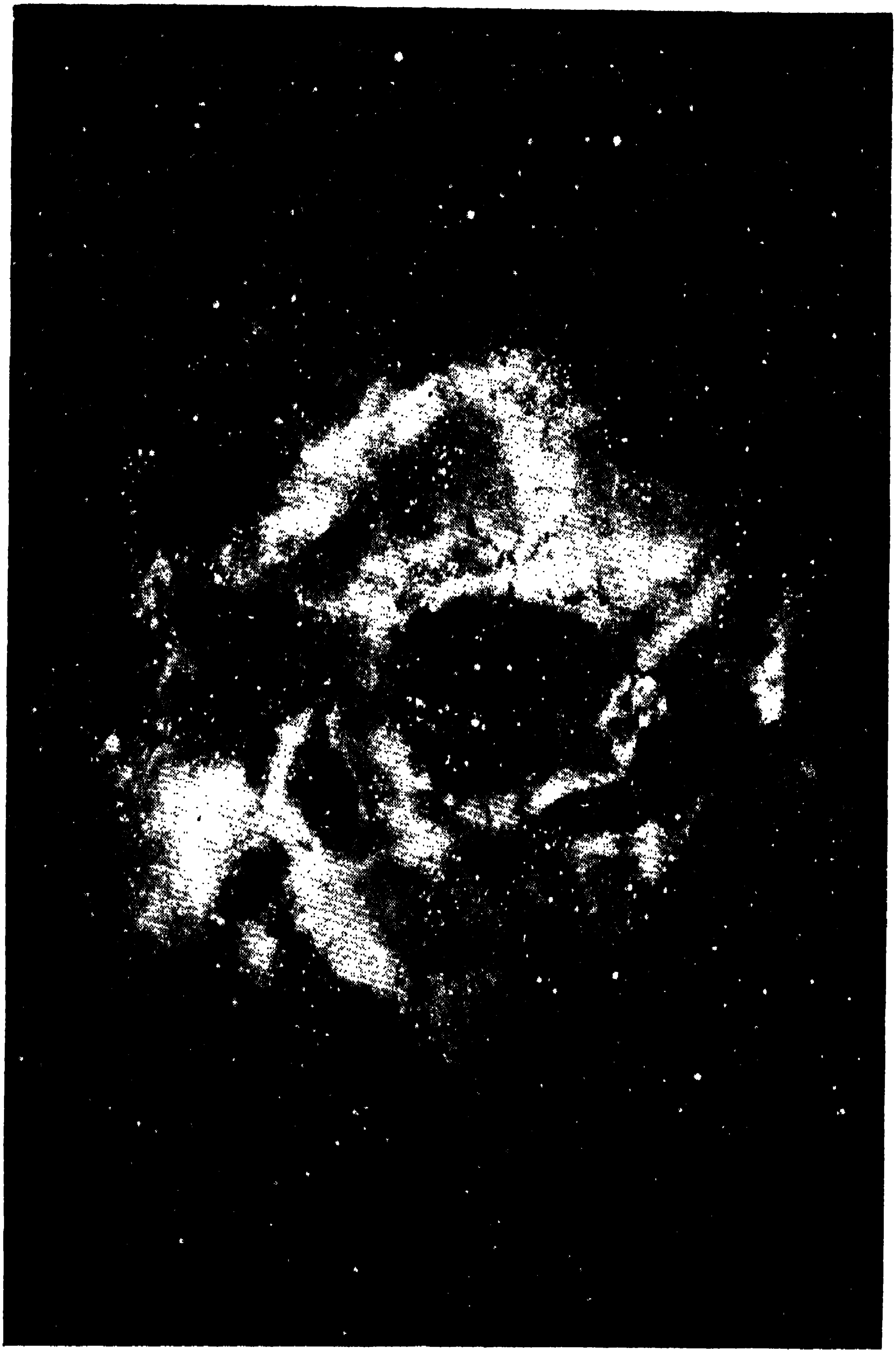

Fig. 17. Nebula in Unicorn

fication of volcanic activity it appears much more probable that in this case the principal factor was the systematic addition of fine volcanic dust to the Earth's atmosphere which resulted in weaker solar radiation on the Earth's surface and at the same time in a sharp increase in the number of nuclei of condensation required for an intense formation of rain.

Thus, as far as we can judge, the familiar sharp changes in the climate of the Earth, which strongly affected the development of organic life on it, were due to internal, mainly tectonic, causes and not at all to any changes in the Sun itself or to the action on it of diffuse nebulae, through which our planetary system has passed in the course of its long existence.

But though the gas and dust clouds do not noticeably affect the stars themselves or the planets by which they are surrounded they may influence the change in the velocity distribution in the Galaxy, causing, for example, the expansion of separate stellar clusters.

There may be a similar question of the possible results of dust and gas clouds meeting each other. These phenomena are inevitable at least because such clouds, unlike stars, have very large volumes compared with their mutual distances. Oort investigated this problem and came to the conclusion that during the meeting of the clouds matter is considerably heated, hydrogen and other atoms noticeably ionize, dust particles evaporate and, thus, cannot grow into larger bodies. According to modern data the gas and dust clouds must meet on the average of once every 5-10 million years.

This process of collision of gas and dust nebulae is of essential importance to the problem under consideration if it occurs on a larger scale between neighbouring Galaxies.

Modern means of research enable us to trace the location of extra-Galactic nebulae, i.e., outer Galaxies all the way to distances of 500 million light-years. In the sphere described by this radius there are at least 100 million Galaxies, divided into three principal types—elliptic, spiral and irregular. There are also Galaxies of the three types in the direct vicinity of our stellar system. Our Galaxy belongs to the spiral category like the large extra-Galactic Nebula of Andromeda located 2 million light-years away. This nebula has two satellites which are elliptic Galaxies. Our Galaxy also has two satellites of the category of irregular Galaxies.

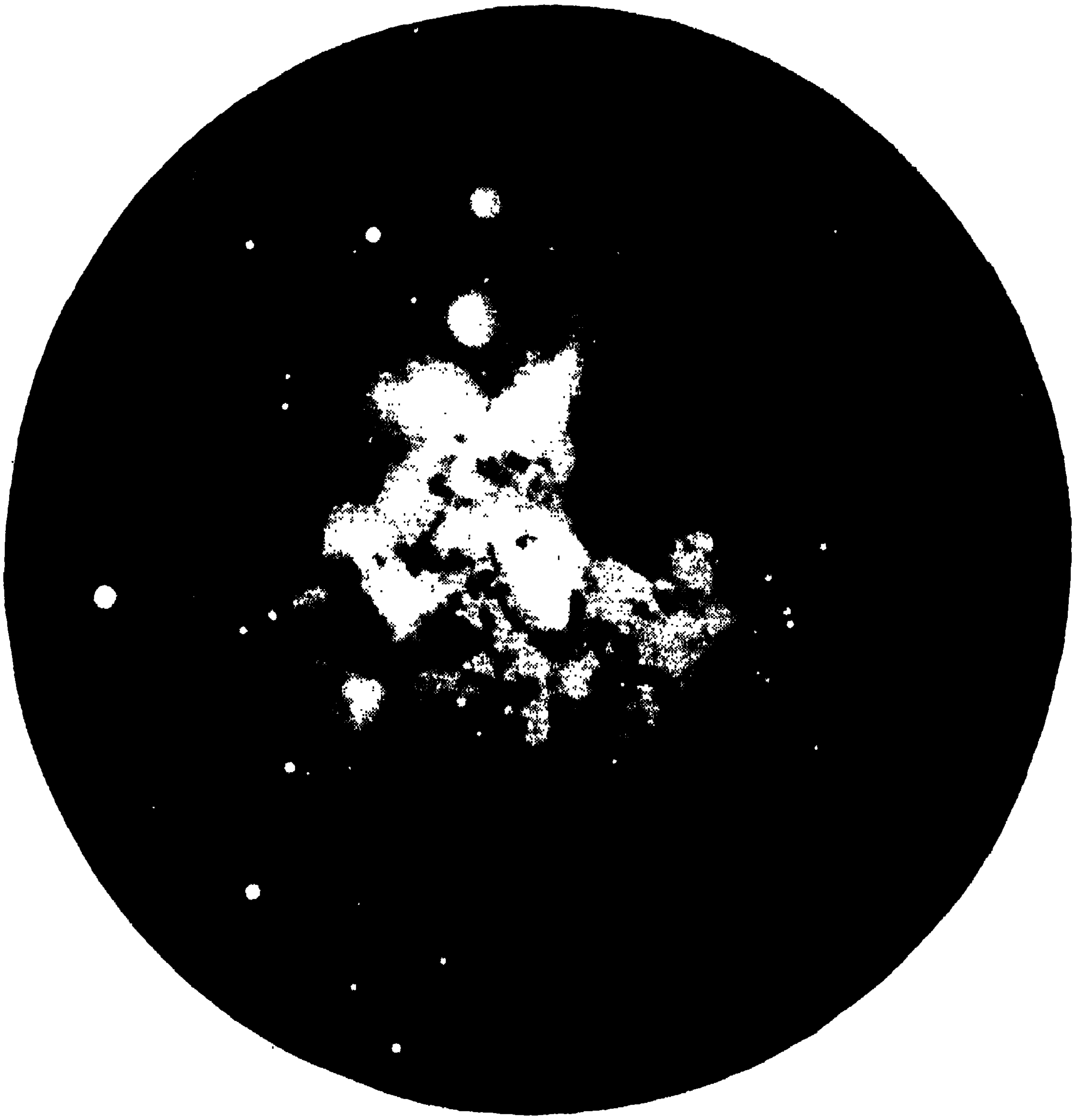

Fig. 18. Central part of the Nebula of Orion

These are the well-known Magellanic Clouds first discovered by Magellan during his round-the-world voyage.

The structure of the Nebula of Andromeda hardly differs from that of our own Galaxy. It is also a flat formation with a very much brighter central nucleus around which the nebula revolves at different speeds depending on the distance from the centre and with a total period of revolution of about 200 million years. In the spiral branches of the Galaxy of Andromeda there are mainly very bright and massive stars with a high temperature; these branches, therefore, have a more bluish colour compared with the central regions. Numerous clusters of stars quite analogous to the stellar clusters in our Galaxy can also be observed in the Galaxy of Andromeda; there are regular and irregular variable stars and extended gas and dust nebulae, as well as long, dark "glades" filled with light-absorbing dust matter. The only difference between the Nebula of Andromeda and our Galaxy is, as has recently become known, that Andromeda's linear dimensions are twice as big as those of our stellar system.

The Galaxies are arranged in the Universe mainly in groups. Our Galaxy also forms part of a small group of 13 objects—three spiral nebulae, six elliptic with different degrees of ellipticity and four irregular. They all consist of stars and gas and dust matter in different proportions. In the space accessible to modern telescopes there are many such, and frequently larger, clusters of Galaxies. In their totality they form the higher system of the Metagalaxy to whose limits even the most powerful telescopes have as yet been unable to penetrate.[1] As has already been pointed out,

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[1] It has been established of late that the Metagalaxy consists not only of the "local" clusters of Galaxies, but also of their larger groups, which have become known as super-Galaxies. For example, the existence of a large system of Galaxies has been established with the centre in the formerly known cluster of Galaxies in the Constellation of Virgo. This system has a diameter of 15-20 million light-years. (*Editor's note.*)

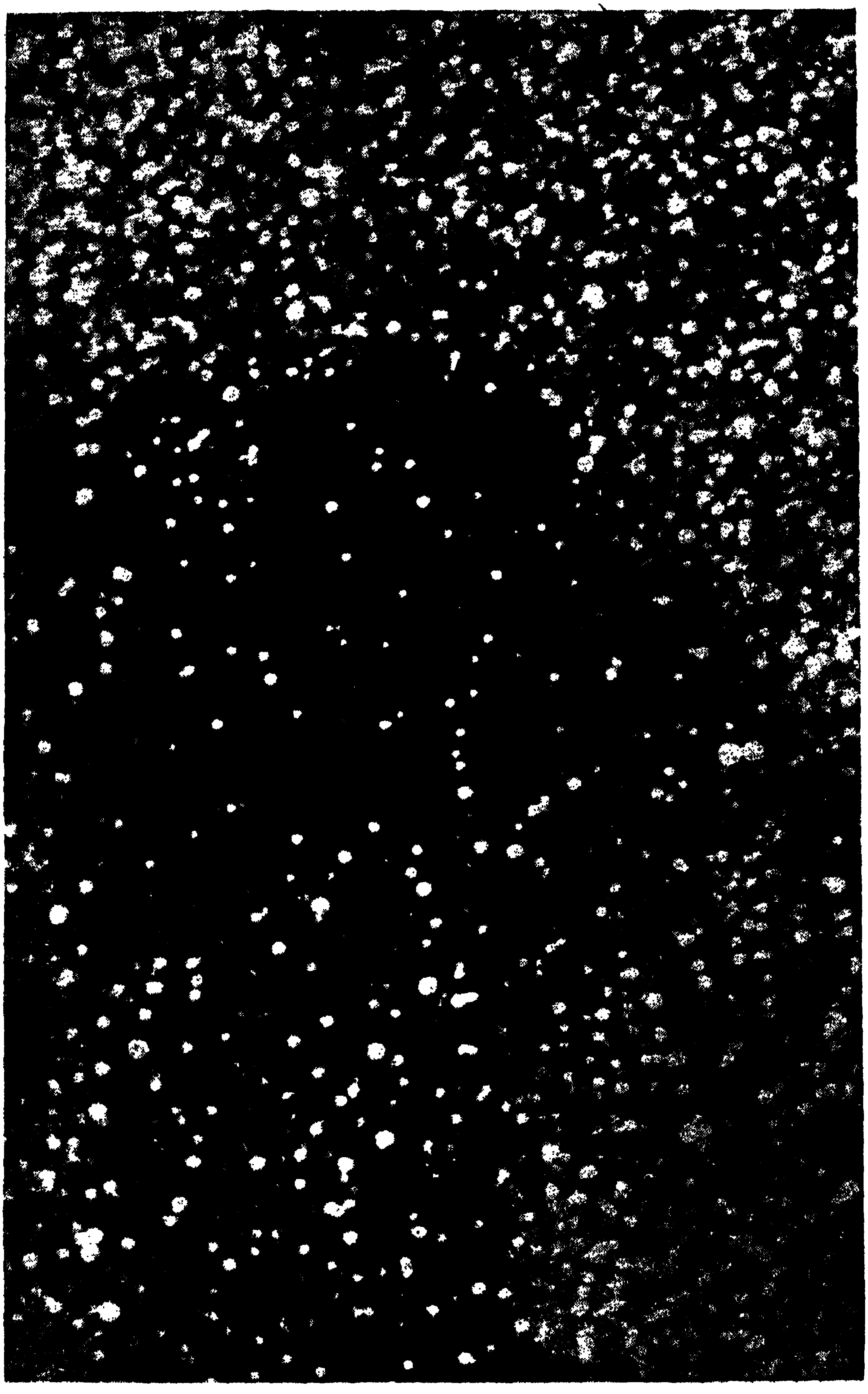

Fig. 19. Dark nebula in Scutum

the distances between the stars in the Galaxies are enormous as compared with the sizes of the stars themselves. Contrariwise, the distances between the Galaxies in the vast Metagalactic system are not so great compared with the dimensions of the Galaxies proper. Thus, for example, the diameter of our Galaxy, as has been mentioned, is about 100,000 light-years, i.e., it is only 1/20 of the distance to the extra-Galactic Nebula of Andromeda. A collision between separate Galaxies is, therefore, not at all impossible, especially since, generally speaking, they move in different directions.

The question is: what will happen if such a collision occurs? Owing to the extremely insignificant sizes of the stars as compared with the inter-stellar spaces one Galaxy may pass through another without in the least affecting their stellar populations. On the contrary, the gas and dust intermediate medium, which fills the inner space of the Galaxy, may be entirely swept out during such a collision. Besides, as it may be supposed, stormy radio-frequency radiation will develop and in the long run the Galaxy will be deprived of its diffuse medium which thus enters the inter-Galactic space. It is hard to say what the results of this may be to the subsequent development of the Galaxies.

The Galaxies, apparently, more frequently exert more or less considerable tidal influences on each other. In such cases the Galaxies that have come close to one another emit tongues of luminous matter towards one another and the adjacent Galaxies appear joined by weakly luminous "bridges," as Zwicky discovered on the photographs of Palomar Observatory.

These "bridges" probably consist of stars ejected from their Galaxies.

Thus, the space between the Galaxies is not absolutely empty. It is filled with a greatly rarefied gaseous medium in which there must be isolated stars that have lost contact with their Galaxies. To leave the limits of their Galaxies stars do not necessarily need strong tidal action by the neighbouring Galaxies. Any star that has acquired sufficient velocity frees itself from the influence of the total attraction of its Galaxy and moves into the inter-Galactic space. Zwicky has found a considerable number of such extra-Galactic

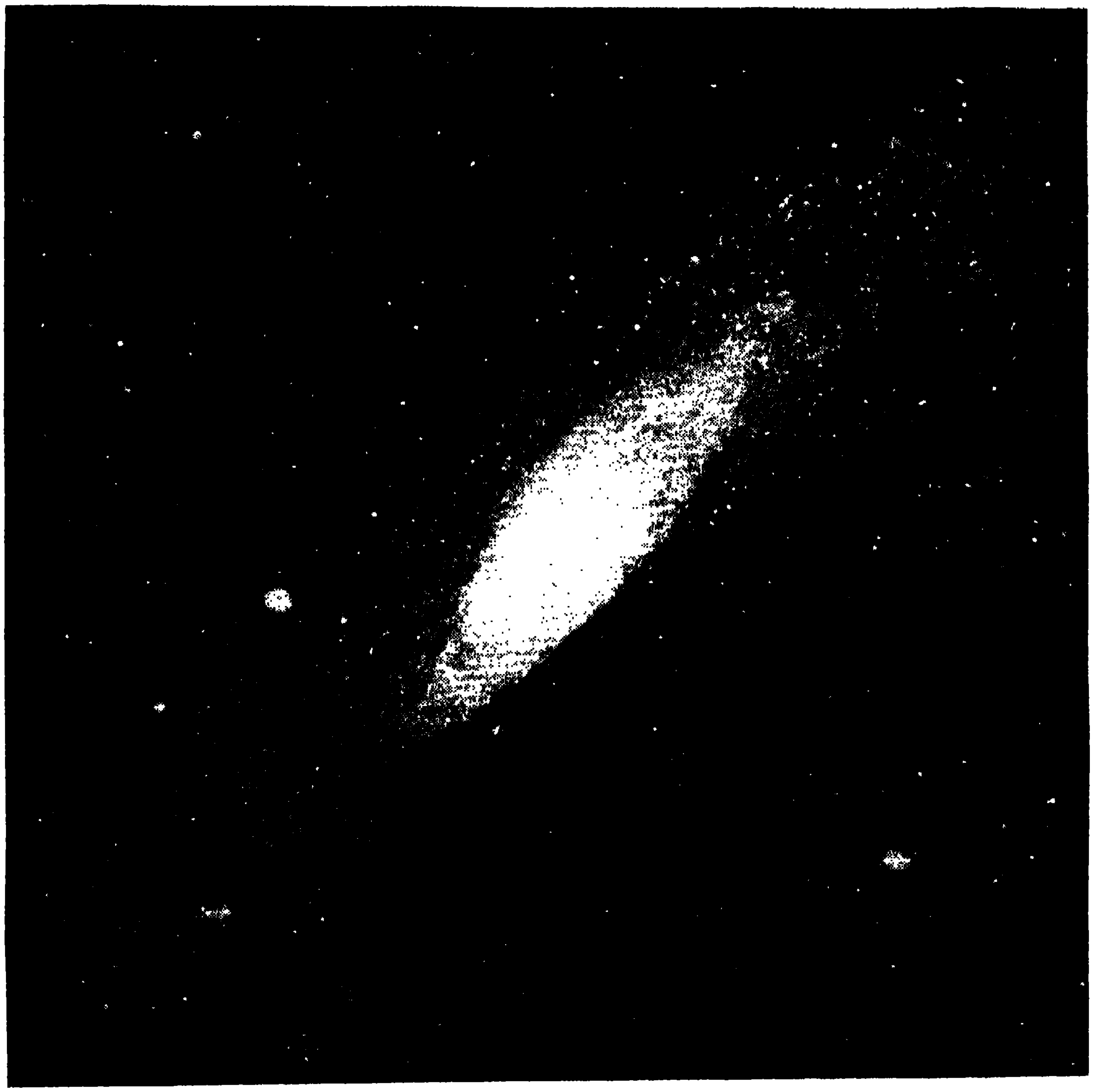

Fig. 20. Extra-Galactic Nebula of Andromeda

stars in the direction of the Galactic Pole. He discovered very weak blue stars without noticeable motion of their own; as a matter of fact, they are giants and are very far outside our Galaxy at a distance of 130,000 light-years and more.

If the Sun and its planets left the Galaxy and went into the infinite spaces of the Universe it would hardly make any

Fig. 21. Accumulations of nebulae near the Galactic Pole

Fig. 22. Close group of Galaxies with intermediate matter in between in the Constellation of Serpent

difference to the conditions of the existence of life on the planets. Instead of the sparkling stars we would see a firmament studded with hardly noticeable nebulous spots—the Galaxies and their clusters. The intensity of cosmic rays would, obviously, noticeably diminish and they would become more directed. It would, probably, have no other effect since we do not very much depend on the other stars of our Galaxy except the Sun.

Chapter III

MAIN FEATURES OF THE STRUCTURE AND ORIGIN OF THE SOLAR SYSTEM

It goes without saying that life is possible only on the surface of a solid body—a planet, surrounded by a gaseous shell and receiving light and warmth from a star with which it is connected. Regrettably, the only planetary system we know of is our own, controlled by the Sun. We shall first dwell in greater detail on the common features of the solar system and shall try to show whether they are of a sufficiently universal nature. For this purpose it is necessary to touch upon the question of the origin of the planets since it is closely connected with the origin of the Sun itself.

Nine planets revolve around the Sun, namely: Mercury (0.39)[1], Venus (0.72), the Earth (1.0), Mars (1.52), Jupiter (5.2), Saturn (9.54), Uranus (19.2), Neptune (30.1) and Pluto (38). Assuming that the planets are heated only by the Sun we can show that their temperature T must change in inverse proportion to the square root of the radius of the orbit r., i.e.,

$$T = \frac{To}{\sqrt{r}},$$

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[1] In the parentheses next to the name of the planet we find the radius of its orbit in astronomical units (distance between the Earth and the Sun).

where T_0 is the mean temperature of the Earth and equals approximately 290° abs.

With the aid of this formula we deduce the following values of the temperature of the planets generally confirmed by radiometric observations.

Planets	Mercury	Venus	Earth	Mars	Jupiter	Saturn	Uranus	Neptune	Pluto
Absolute temperature . . .	464	342	290	235	127	94	66	53	47
Temperature in °C . .	+191	+ 69	+ 17	— 38	—146	—179	—207	—220	226

We are deducing these approximate mean temperatures which depend only on the distances of the planets from the Sun, on the assumption that all the other physical properties of the planets are the same. As a matter of fact, the temperature may considerably change on each planet depending on the peculiarities in its structure, period of rotation and composition of its atmosphere. For example, on Mercury, which has no atmosphere at all and which is always turned to the Sun with one side, the temperature at the point of surface for which the Sun is in the zenith reaches 670° abs., while on the opposite (the night) side it may be close to zero. Even on the Moon, which has neither atmosphere nor water, the maximum temperature of the surface at the equator at noon rises to above 100°C, but during the long lunar night or lunar eclipses it drops to—140°C. Nonetheless, the table given here offers a generally correct orientation in the temperature conditions on the planets.

The planetary orbits are noted, primarily, for their considerable regularity and stability. They are nearly circular and are located approximately in the same plane. Only

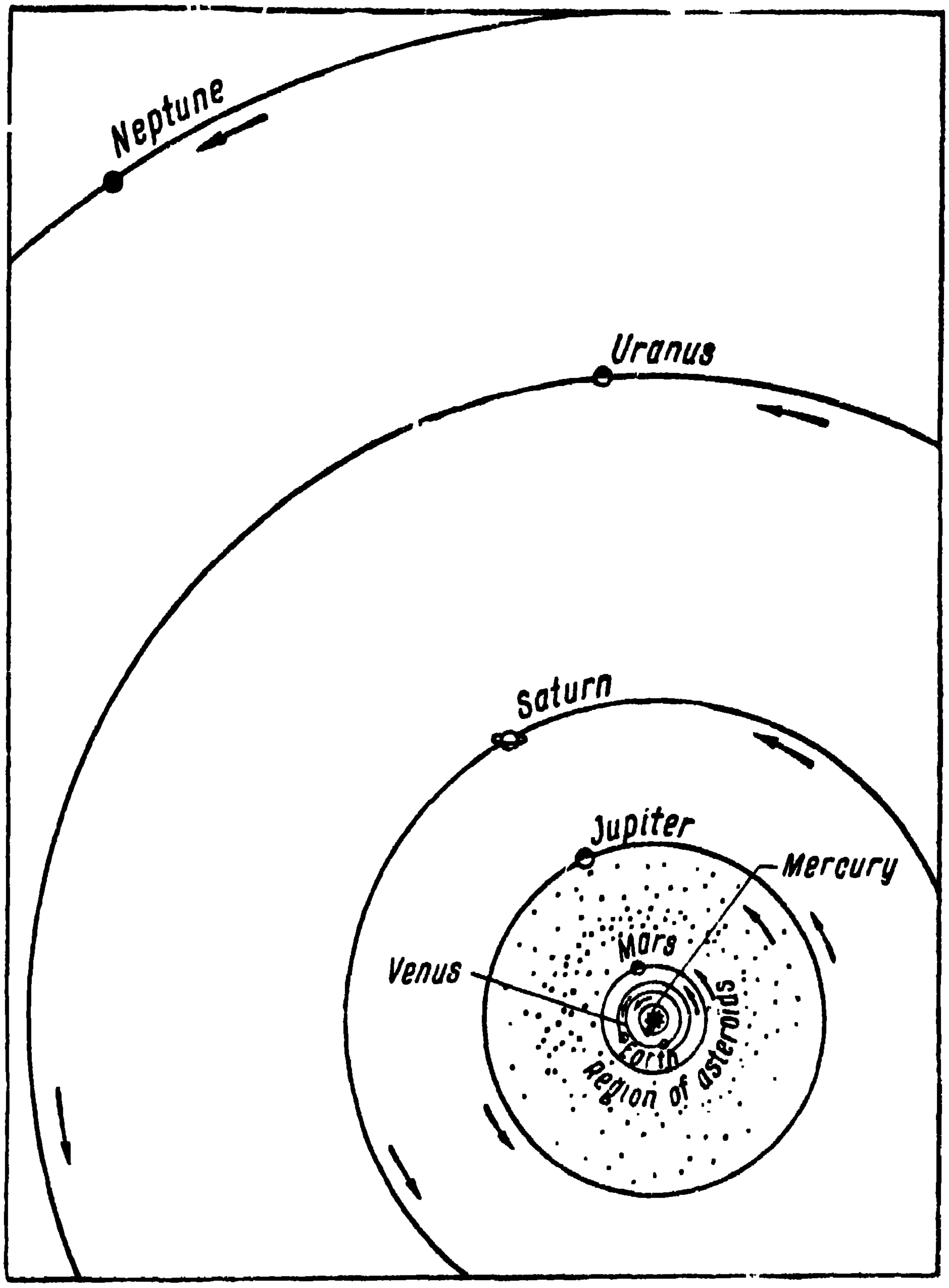

Fig. 23. Diagram of the solar system

Mercury and Mars revolve on more elliptic orbits and the greatest distances of these planets from the Sun differ by 20.6 per cent and 9.3 per cent from their mean distances respectively.

The orbits of the other planets, especially those of the Earth, Venus and Jupiter, are so close to circular that they cannot be distinguished from them when represented graphically. Owing to this each planet receives approximately a constant inflow of radiation from the Sun. The observable seasonal changes in the climate depend only on the angle of inclination of the planet's equator to the plane of its orbit, but these angles are not particularly large; for example, for the Earth it is 23.5°, for Mars—25.2°, and for Jupiter—only about 3°. Thus, Jupiter's equator nearly fully coincides with the plane of its orbit and the planet, therefore, has actually no seasonal changes in temperature. Uranus is the only exception because its equator is inclined to the plane of its orbit almost at a right angle so that during a full revolution of this planet the Sun passes through the zenith of any point of its surface twice. But Uranus is so far from the Sun that this circumstance does not affect the temperature of its surface.

The fact that the masses of the planets are very small in comparison with the mass of the Sun and that the planetary orbits are separated from each other by large intervals is of enormous importance. The mass of the Sun is 800 times as great as that of all the planets and its gravity ensures the stability of the solar system. The mutual attractions between the planets are small and are able to cause but insignificant perturbations in their motion which, besides, are of a periodic nature. The inferences of celestial mechanics prove that the planetary perturbations do not affect the distances between the planets and the Sun and are unable to upset the integrity of the solar system. The ratios of the radii of the planetary orbits may, therefore, be considered a characteristic feature of the solar system retained all through its existence. The ratio depends, to some extent, on the masses of the planets. For the larger planets (Jupiter, Saturn and Uranus) the ratio of the radii is close to 2, whereas for the planets with an insignificant mass (Venus, Mars and the Earth) this ratio is close to 1.5. All these peculiarities must be explained in the theory of the origin of the solar system.

Between the orbits of Mars and Jupiter there is a large "glade" whose existence clearly upsets the general regularity in the distribution of the planetary distances. But as a result of the investigations conducted in the 19th and

Fig. 24. The Sikhote-Alin Meteorite Crater

20th centuries it was established that a vast number of small planets—asteroids—revolves in this "glade." In most cases the asteroids are angular fragments of irregular form. For example, the asteroid Eros, which comes rather close to the Earth every 30 years and is therefore particularly suitable for the precise calculation of the scale of the solar system, is shaped like a rod, or rather a cucumber 10 kilometres long and 5 kilometres wide; like many other asteroids it takes a few hours to rotate on its axis. The smallest observable asteroids are approximately 1 kilometre in diameter, but there are, undoubtedly, numerous smaller ones.

It is commonly believed that these small bodies are the shattered remains of a formerly existing planet. This breaking up continues to-date because of mutual collisions and as a result the solar system is replenished with extremely small fragments, as fine as dust.

It has been shown that fine dust particles are noticeably inhibited in the light field of the Sun and gradually gravitate towards the Sun and settle on its surface. These particles sometimes penetrate at a great speed into the atmosphere of the Earth and they are then observed as meteors, or as they were formerly called, shooting stars.

Rather large meteorites fall sometimes, as was the case, for example, on February 12, 1947, when a rain of meteorites with a total mass of at least 150 tons fell on the Earth. In their fall large fragments formed close to 110 craters in the rocks of the Sikhote-Alin Mountain Range. But despite the fact that the meteorites penetrated into the Earth's atmosphere with a velocity of only about 14 km/sec the greater part of them dissipated in the air and only about 10 per cent of their mass fell on the surface of the Earth.

Examinations of the meteorites have shown that they have a very complex chemical structure with the different elements in definite proportions. The ratios between iron, nickel, cobalt and other elements, sometimes contained in the meteorites in negligible admixtures, but in strictly fixed proportions, could have come about, according to the unanimous opinion of mineralogists and geochemists, only in an originally molten medium. We must consider the fact that during their long travels in the solar system the meteorites may have been remelted when approaching too close to the Sun and their original structure may, in a number of cases, considerably have differed from their present state. This complicates the study of the mineralogical peculiarities of meteorites, but it may be taken for granted that their chemical composition had not suffered any changes save the gases contained in them.

Today we have convincing proof that the meteorites are fragments of a formerly existing planet which broke up most probably from a strong shock received in a collision with an analogous body. This proof is connected with the computation of the "age" of the meteorites. The age can be computed, primarily, by the presence in the meteorites of the rare He_3 isotope which is a result of the irradiation of the atoms of iron by cosmic rays during the long wanderings of the meteorites through inter-planetary space. This isotope, as is well known, cannot be produced as a result of ordinary radio-active disintegration. On the other hand, the age of the meteorite can be calculated by the radioactive method according to its relative content of lead. It turned out that the meteorites, as determined by the first method, were not over 300-400 million years old. But in

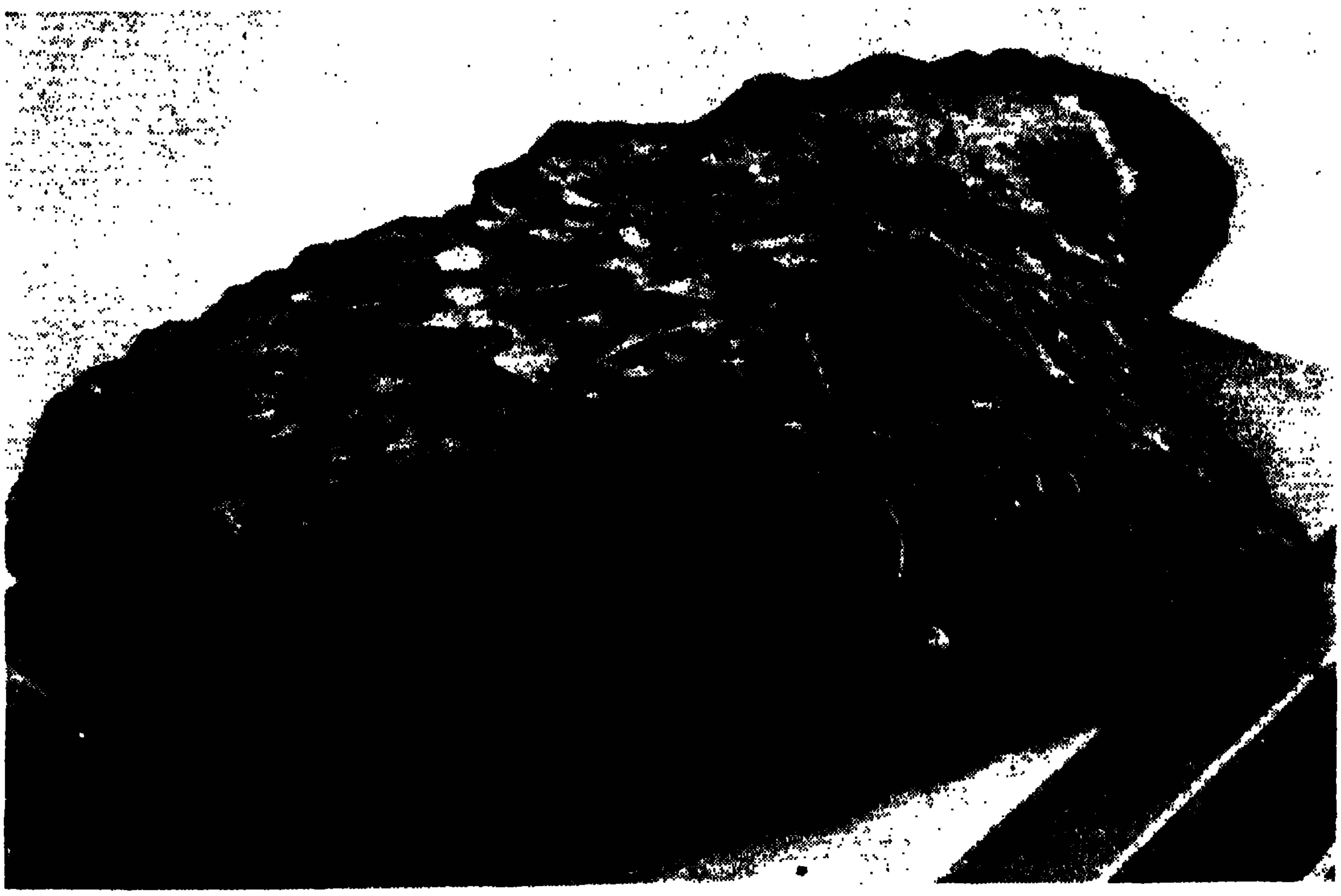

Fig. 25. Large meteorite of the Sikhote-Alin Iron Rain

this case by the "age" we do not imply the time the substance of the meteorite has existed, but rather the duration of its wanderings through inter-planetary space. According to the second method the meteorite is about 4,000 million years old, i.e., its age corresponds to the period since the substance of the meteorite had existed in the entrails of its mother-planet. It is possible, however, that there were several planets, from which the meteorites sprang as a result of their break-up and that the last big collision occurred about 300 million years ago.

Thus, the individual asteroids which came into being in the region between the orbits of Mars and Jupiter were probably relatively few and were much larger than most of the similar bodies existing today and continuing to break up into ever smaller fragments, down to meteorites and even smaller cosmic dust.

We shall now briefly describe the large bodies of the solar system. The large planets can be divided into two groups with essentially different physico-chemical properties. The planets of the "terrestrial" type, which include Mercury, Venus, the Earth and Mars, i.e., the planets closer to the Sun, are noted for their small masses (the largest of these is the Earth whose mass is 330,000 times as small as that of the Sun), relatively slow rotations and great densities because they are made up of heavy elements. Their atmospheres are insignificant in their masses and volume as compared with the masses of the planets as a whole and are of secondary origin, i.e., they were formed after the origin of the planets, in the course of the evolution of the planets.

The superior planets—Jupiter, Saturn, Uranus and Neptune—are distinguished for entirely different properties. They have very large masses (for example, the mass of Jupiter is 318 times as great as that of the Earth), rotate very rapidly around their axes (Jupiter rotates around its axis in 9 hrs 50 mins) and, therefore, have a very big reserve of rotation energy. Despite the great internal pressure the mean densities of these planets are very low (for example, the density of Saturn is only 0.7 that of water). This is due to the fact that they are made up chiefly of the lighter gases—hydrogen and helium—and have a certain admixture of heavier elements only in their interiors.

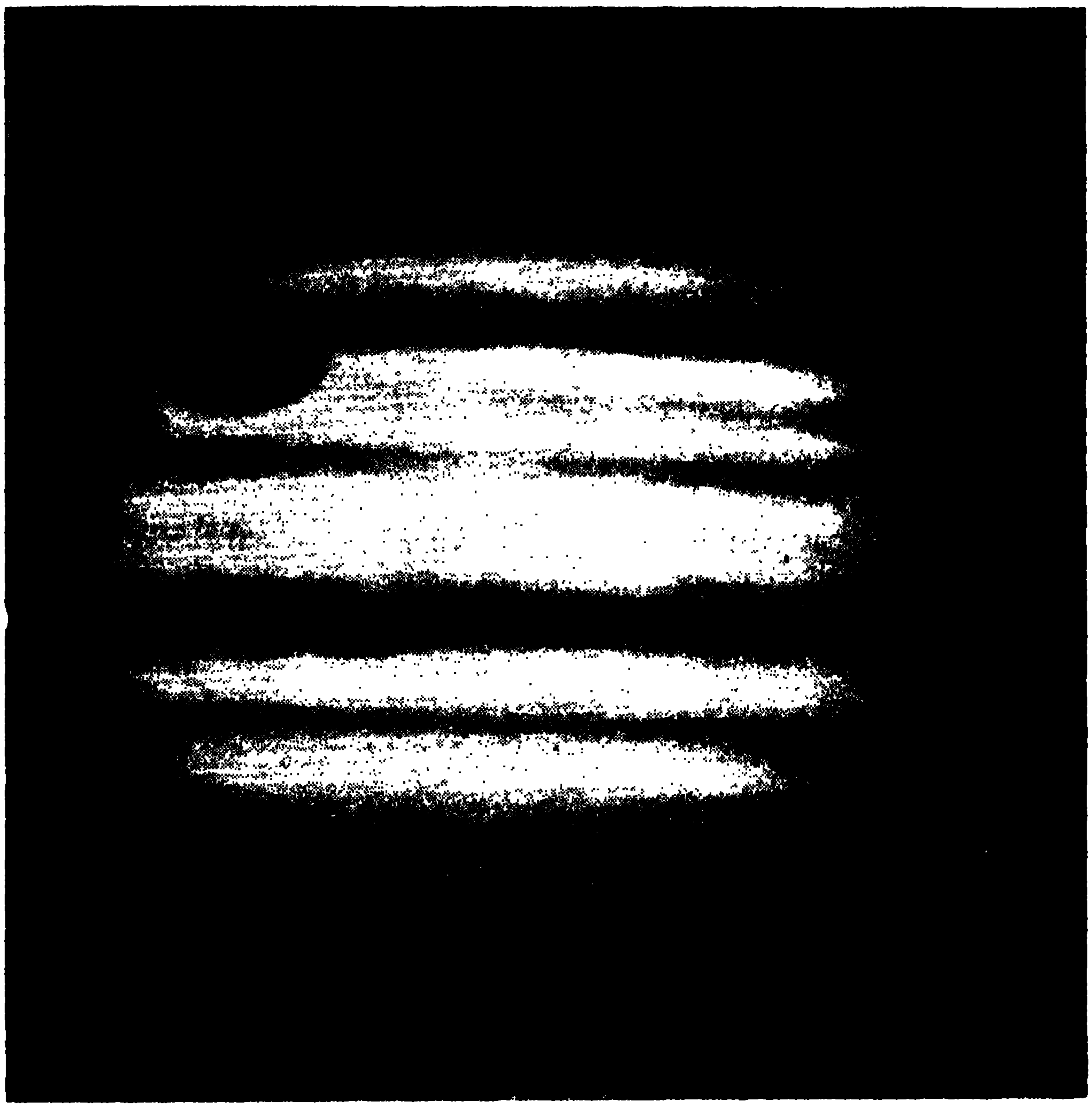

Fig. 26. Jupiter

The question of the chemical composition of the large planets is of great importance in ascertaining the origin of the solar system. The masses of Jupiter and Saturn constitute the main part of the entire mass of the planets of the solar system and, therefore, characterize to the greatest extent the composition of the primary environment which had served for the formation of the planets. This problem could not be solved until recently because it was not known how an ordinary solid body behaved under pressures existing inside the planets, i.e., of millions and tens of millions of atmospheres. This question is being answered today on the basis of experiments ascertaining the behaviour of solid bodies under pressures of hundreds of thousands of atmospheres and the theoretical considerations growing out of our knowledge of the structure of substance. For Jupiter, whose rotation, mass, size and degree of oblateness at the poles are well known, it is possible to establish the chemical composition and the distribution of densities at different distances from the centre.

By the shape of the planet (the degree of its oblateness at the poles) and rate of rotation it is possible to judge the degree of heterogeneity of its internal structure. The planet will be the more flattened the more homogeneous it is, i.e., the greater the part of its mass is concentrated in the outer layers farther from the centre and the more it is, consequently, subject to a greater centrifugal force. The ellipticity of Jupiter, i.e., the excess of its equatorial radius over the polar, equals one-sixteenth. But if Jupiter were more homogeneous it would be more oblate. Without any particular conjectures concerning the behaviour of its substance under changed pressure we can determine the degree of heterogeneity in the structure of this planet on the basis of

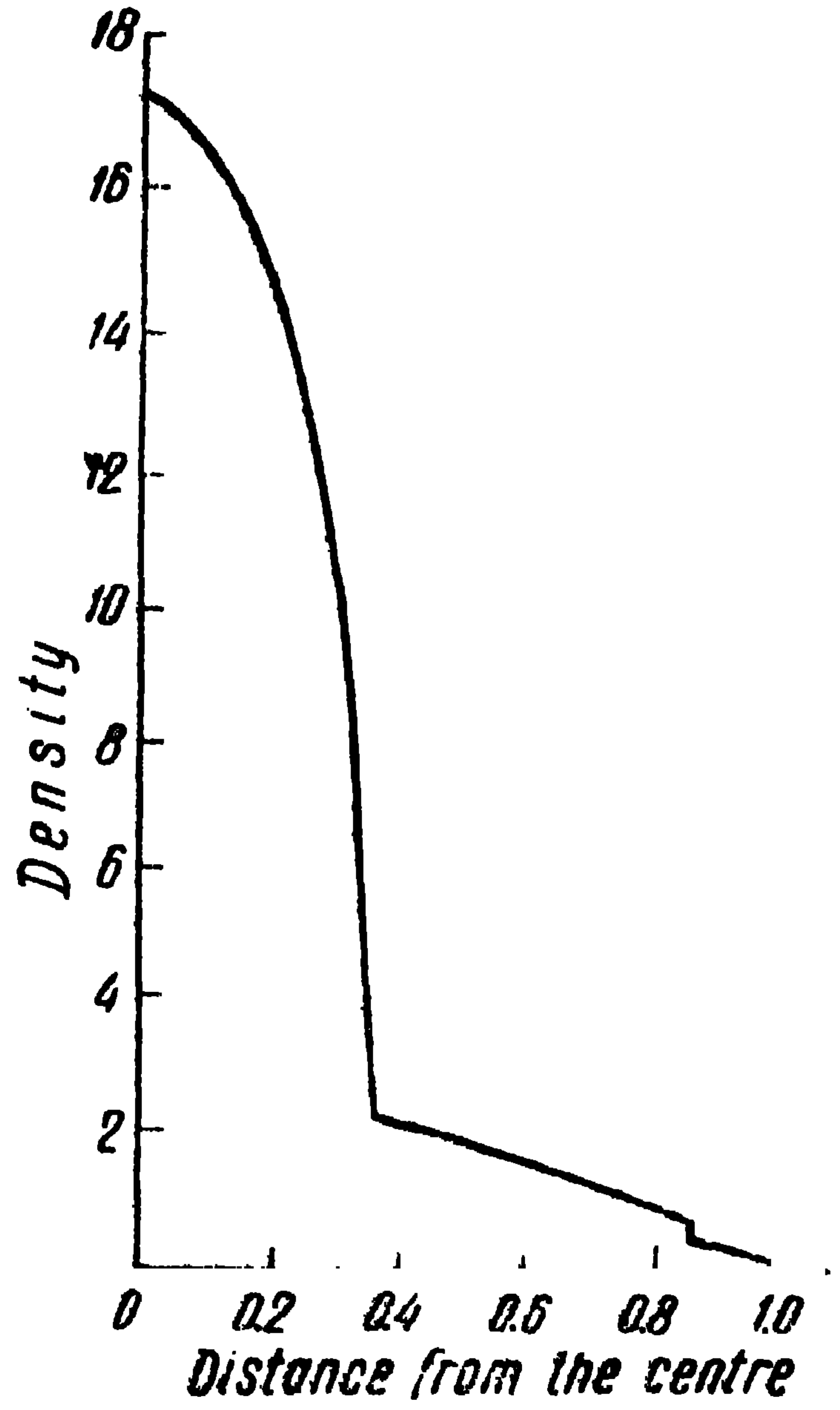

Fig. 27. Internal structure of Jupiter

mechanical laws alone. It appears that in its structure Jupiter is more heterogeneous than the Earth or any other planet of the terrestrial group. Thus, by determining the degree of Jupiter's heterogeneity we can very easily find the lower and upper limits of hydrogen it contains.

We get the lower limit by the doubtful assumption that the substance in the central parts of Jupiter is absolutely incompressible, i.e., this planet despite its enormous internal pressure consists of homogeneous layers. In this case, as was shown long ago by Wildt, the mass of Jupiter must consist one-third of hydrogen.

We obtain the upper limit of hydrogen content by the reverse assumption that all of Jupiter's substance is in an absolutely degenerated state, i.e., that its atoms are completely crushed, in other words, their nuclei are separated from the electrons. In this case a theoretical investigation of the problem shows that Jupiter and Saturn may essentially consist only of hydrogen with a very small admixture of heavier elements. Uranus and Neptune, other planets of the same group, which have a somewhat smaller mass, are noted for containing a lower percentage of hydrogen and helium. It appears at the same time that the mass of the large planets can in no way wholly consist of compounds of hydrogen with other gases, for example, of hydrocarbons.

In studying the equation of the state of hydrogen under different pressures we may try to build a purely hydrogen model of Jupiter in which both the mass of the planet and its radius with the observable degree of heterogeneity should be reproduced. As a result of a detailed analysis we find that Jupiter probably contains 85 per cent of hydrogen with the remaining 15 per cent belonging to helium mixed with other heavier elements. Besides, the outer layers of the planet to a depth of 0.86 of its radius from the centre, or 0.14 of its radius from the surface, consist mainly of molecular hydrogen. At this depth the density reaches 0.4 of the density of water.

This is followed by a leap in the value of the density due to a change in the state of hydrogen—its transition into an atomic state, the so-called metal phase, when, owing to the tremendous pressure, which reaches 700,000 atmospheres on this level, the electrons "free themselves," as it were, and are no longer bound to definite atomic nuclei. During the transition into the metal phase the density of hydrogen doubles. Subsequently the density continually increases to the depth corresponding to 0.29 of the planet's radius from the centre, which is followed by a new uneven change in the transition toward the central part of the planet now consisting of a mixture of hydrogen and other, heavier elements.

We may add to these purely theoretical calculations that recent direct observations established the general approximate chemical composition of Jupiter's atmosphere by its mean molecular weight. This mean molecular weight can be found by determining the refracting ability at different altitudes of this planet's atmosphere, which is quite definitely established by occultation of the stars by the planet.

When the disk of Jupiter approaches a star the latter does not disappear at once because the rays of light emanating from the star at first pierce the high and relatively rarefied layers of the atmosphere and refract in it differently, according to the distance from the edge of the disk. Due to the difference in refraction the beam of rays after going through the atmosphere of the planet comes out of it in the direction of the observer already somewhat diverging, which due to the great distance between Jupiter and the Earth rapidly makes the star lose in brightness. Precise records of this diminution of the star's brightness make it possible in time to determine the refracting ability of Jupiter's atmosphere and, consequently, the corresponding molecular weight. As early as 1937, the British astronomer Pick thus found the value of about 4 for the mean molecular weight, which corresponds to 6 molecules of hydrogen H_2 for one molecule of methane CH_4, whose content is very clearly visible in Jupitér's spectrum.

On November 20, 1952, when Jupiter occulted the rather bright α Arietis Baume and Code calculated more accurately that the mean molecular weight was 3.3. For the sake of comparison we may recall that the mean molecular weight of the terrestrial atmosphere composed of 21 per cent oxygen and 79 per cent nitrogen in a molecular state is nearly 10 times as high, namely, about 30. It clearly follows that Jupiter's atmosphere must contain greater quantities of hydrogen. Thus, for example, by taking into account the relative abundance of various elements in the Universe the established molecular weight may be presented in the following proportions:

molecular hydrogen	100 molecules
helium	20 molecules
other, heavier compounds	7 molecules

These heavier compounds include methane CH_4 and ammonia NH_3, which, owing to their weak molecular bonds, are stimulated by insignificant radiation of the Sun and can, therefore, be well seen in the spectra of all large planets beginning with Jupiter.

Direct spectroscopic proof of the presence of hydrogen in the spectra of the major planets has been obtained only for Uranus and Neptune, and only very recently at that.

As established by Kuiper a band is observed in the spectrum of Uranus and Neptune in a 8,270 Å wave-length. A number of experiments conducted by Hertzberg in a laboratory with liquid nitrogen at a temperature approximating that of the atmosphere of these planets showed that this band must be ascribed to molecular hydrogen. Next to this band, however, there must be another band of molecular hydrogen in the 8,166 Å wave-length, which is not observable in the spectrum of Uranus and Neptune Experiments show that this second band is infallibly weakened, and very considerably, indeed, if some neutral gas, whose atoms repeatedly collide with the molecules of hydrogen, is added to the molecular hydrogen. This effect is best produced by the admixture of helium; besides, for an explanation of the observable spectral peculiarities it is necessary that the atmospheres of the aforesaid planets contain approximately 3 times as much helium as molecular hydrogen.

It, therefore, follows that there is a certain interdependence between the mass of a large planet and the quantity of light gases it contains, and the most demonstrative of these is, of course, hydrogen.

The content of different elements in the planets of the terrestrial type is entirely different. For example, the elements prevailing on the Earth are those, which condense into liquid and solid states at high temperatures, as well as oxygen, which is still capable of entering into stable compounds at high temperatures. All the elements, beginning with hydrogen, whose temperature of liquefaction is sufficiently low and which cannot form stable compounds with metals at high temperatures, are very rare on the Earth compared with their content on the Sun and on other stars.

Besides, it is very important to note that the distribution of the widespread elements is exactly the same on the Earth as it is on the Sun. Russel, who was one of the first to make a quantitative chemical analysis of the solar atmosphere, noticed that all the elements with a high temperature of liquefaction, which were most widespread on the Sun, were similarly plentiful on the Earth. To illustrate this remarkable correlation he chose 14 elements of this type and divided them into three groups according to the degree of their abundance. The following correlation for the Sun and the Earth was obtained:

Group I	*Earth*	*Sun*
(most widespread elements)	Iron	Magnesium
	Aluminium	Iron
	Nickel	Potassium
	Calcium	Calcium
	Sodium	Aluminium
	Potassium	

Group II	*Earth*	*Sun*
(less widespread elements)	Titanium	Manganese
	Chromium	Nickel
	Manganese	Chromium
	Cobalt	Cobalt
		Titanium
Group III		
(the least widespread elements)	Copper	Vanadium
	Vanadium	Copper
	Zinc	Zinc

We really see that in all three groups the elements are grouped almost analogously. The chemical analysis of meteorites, which are but fragments of cosmic matter falling on the Earth, shows the same order of distribution of elements with a high melting temperature. This comparison can be continued with rarer elements not represented in the given table. The results are similar.

Only four elements form an exception, since their comparative distribution on the Sun and on the Earth differs. These are the elements, however, of whose distribution on the Earth we do not know enough. It is, therefore, hardly possible to state with any degree of certainty that there are relatively greater quantities of any metal on the Sun than there are on the Earth.

This surprising correspondence between the Sun and the Earth in the relative abundance of elements with high melting temperatures may be regarded as vivid proof of the common origin of our Sun and the planets by which it is surrounded. The Sun and the planets had to form from some common material characterized by a content of various elements which is generally peculiar to the Universe as a whole. The sharp discrepancy between the Sun and the Earth as regards the distribution of the elements with a low temperature of liquefaction has other reasons.

Despite the fact that hydrogen is the most widespread element in the Universe and abounds on the Sun and on the big planets, there is relatively little of it on the Earth. The total quantity of hydrogen in the Earth's crust and in the oceans occupies only the eighth place among the other elements. Oxygen, which constitutes at least 51 per cent of the weight of the Earth's crust, because of its enormous chemical affinity, stands first.

It may seem strange that even such inert elements with a very high molecular weight as argon, neon, crypton and xenon rather widespread in the Universe are very poorly represented on the Earth. Argon, which forms approximately one per cent of the Earth's atmosphere, is, as is well known, of a radio-active origin and has formed during the long history of the Earth as a result of the disintegration of radio-active potassium with the atomic weight 40. Neon, which is, certainly, of no radio-active origin and is very abundant in the Universe, is represented on the Earth by an absolutely negligible quantity. We can judge about the quantities of these inert gases on the Earth by determining their content in the Earth's atmosphere, or in the different minerals which form part of the Earth's crust, or, finally, by analyzing the different natural gases liberated from wells and bore-holes. The relative abundance of these gases has been found approximately the same in all cases. To determine the relative content of these gases on the Earth and in the Universe it is most expedient to take the content of silicium as a unit because it is one of the basic elements in the Earth's crust and is also found in cosmic space. To make the data obtained somewhat more precise we can use the definite correlations between the abundance of the elements and their atomic weights established for the Universe. It was established, for example, that the discrepancy between the content of neon in the Universe and on the Earth constitutes a magnitude of approximately 10^{10}. This means that the Universe, or, to be more precise, its part which is accessible to study, contains 10,000 million times as much neon in comparison with silicium as does the Earth. The magnitude 10^6 has been similarly found for crypton, the heavier inert element.

These inert gases, which are not liberated from the interior of the Earth as a result of tectonic activity and do not form compounds with other elements must, apparently, characterize the fate of our planet's original atmosphere. The other elements—nitrogen, oxygen, carbon dioxide and water vapours which make up our air shell today—are not characteristic in this respect since the relatively inert nitrogen is emitted in large quantities from various tectonic holes, oxygen is emitted in a free state as a result of the activity of plants (photosynthesis), while the inconsiderable amount of carbon dioxide is explained by processes of combustion, including living organisms, and by emission from the interior of the Earth which is observed in every manifestation of volcanic activity. It should be noted that any cooling of lava, any volcanic eruption is necessarily accompanied by discharge of water vapours into the atmosphere. Thus, the present-day composition of the earthly atmosphere has formed in the course of geological epochs and is, undoubtedly, of a secondary origin sharply differing from the composition of the atmosphere of the primeval Earth.

It may seem strange that the Earth's atmosphere was unable to retain even such heavy gases as xenon and crypton in their original quantity; nevertheless, the relative content of these gases on the Earth is almost the same as in cosmic space. There can be only one reason for this. The dissipation of our planet's original atmosphere did not occur separately for each gas, but was determined exclusively by hydrogen, by far the most abundant element, that must have carried away with it all the other gases, which constituted relatively insignificant admixtures. Even today, due to the inevitable turbulence of the atmosphere the distribution of different gases in it is in no way connected with their molecular weights. Thus, for example, so heavy a gas as carbon dioxide is contained, as experiments have

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shown, at an altitude of 20 kilometres in the same relative quantities as on the surface of the Earth. The mean molecular composition of the atmosphere remains nearly constant up to the highest altitudes despite the fact that it contains gases of different atomic weights. It must be likewise assumed that during the intensive dissipation of hydrogen from the original planetary condensations or from already formed planets it carried away with it other gases irrespective of their atomic weights. If we agree with this we will have to accept that the basic element, which determined the ultimate chemical composition of the planets, was precisely hydrogen because of its original abundance.

As we have pointed out hydrogen, though the most widespread element in the Universe, stands only eighth among the other elements on the Earth and this is, apparently, due to the fact that the Earth was formed as a body of a relatively small mass. If we now turn to Mars, whose mass is only one-ninth that of the Earth, we shall find confirmation of the aforesaid regularity. As a matter of fact, there are no open water basins, no rivers or streams with free water on Mars and with its rarefied atmosphere which, apparently, consists, mainly, of nitrogen it contains so little water vapours that they can produce only a very thin layer of rime. Even the so-called polar snows on Mars, which thaw out completely despite the very low temperature on this planet, are made up of a layer of snow and ice at best only several centimetres thick. It is, thus, perfectly clear that there is much less hydrogen on Mars than there is on the Earth and this is most probably due to the original conditions under which the planet was formed. And finally the Moon whose mass is one-eightieth that of the Earth is absolutely deprived of an atmosphere and the content of hydrogen on it, even in the form of any compounds in its crust, is, apparently, close to zero. Incidentally, fully to back up this conclusion concerning the Moon we must know how it formed since the Moon is not an independent planet and the composition of its rocks may have been to some extent borrowed from the Earth if both these bodies had a common origin in a condensed clot of matter. It was formerly supposed on the basis of George Darwin's Tidal Theory that the Moon was born from the Earth and that it sprang from the region that is now the Pacific Ocean. This point of view is now no longer acceptable, but the common formation of both bodies appears quite probable. We may analogously think that one of the most massive satellites in the solar system—Titan (Saturn's satellite)—could also in some measure have borrowed from its planet the methane atmosphere which it is still able to retain because of its low temperature.

At any rate it is quite obvious that the content of hydrogen and, at the same time, the density and extension of a planet's atmosphere are in a definite manner connected with its mass. With a smaller mass the planet received less hydrogen at the time it was formed. Jupiter, whose mass is about 2×10^{30} g, has a nearly normal quantity of hydrogen, maybe only a little less than the mean quantity of this element in the Universe. On Uranus and Neptune, whose masses are approximately 1/15-1/16 that of Jupiter, the content of light gases, and especially hydrogen, is already noticeably lower. On the Earth with its mass 1/318 that of Jupiter hydrogen already occupies the eighth place, but its abundant combinations with oxygen are still possible in the form of oceans; Mars with its still smaller mass hardly has any hydrogen and its compounds, primarily water, though in Mars' rarefied atmosphere there are other gases, most probably, of a tectonic and radio-active origin. The Moon whose mass is 1/80 that of the Earth has no atmosphere whatsoever. The approximate correlation between the content of hydrogen and the mass of the planet may be represented graphically (Fig. 28), where the logarithm of mass expressed in grams is placed on the axis of the abscissa.

The origin and development of life on a planet requires, other conditions being equal, that it have a mass approximately 10^{27}-10^{28} g (for our solar system). The mass of a livable planet must be on the lower end of the curve of hydrogen content, though not at the very bottom.

A planet which unites all the elements in their natural abundance is not fit for life, because its gas and cloud shells are too large and there is actually no hard surface containing the compounds of metals. So hard a surface could have formed, for example, on Jupiter at so great a depth that the pressure of the upper layers would have crushed the electronic shells of the stablest atoms and the formation of any complex and, therefore, unstable albuminous compounds would have been absolutely impossible. If the mass of a planet is too small there will be no atmosphere on it at all or it will be at least insufficient and unfit for life.

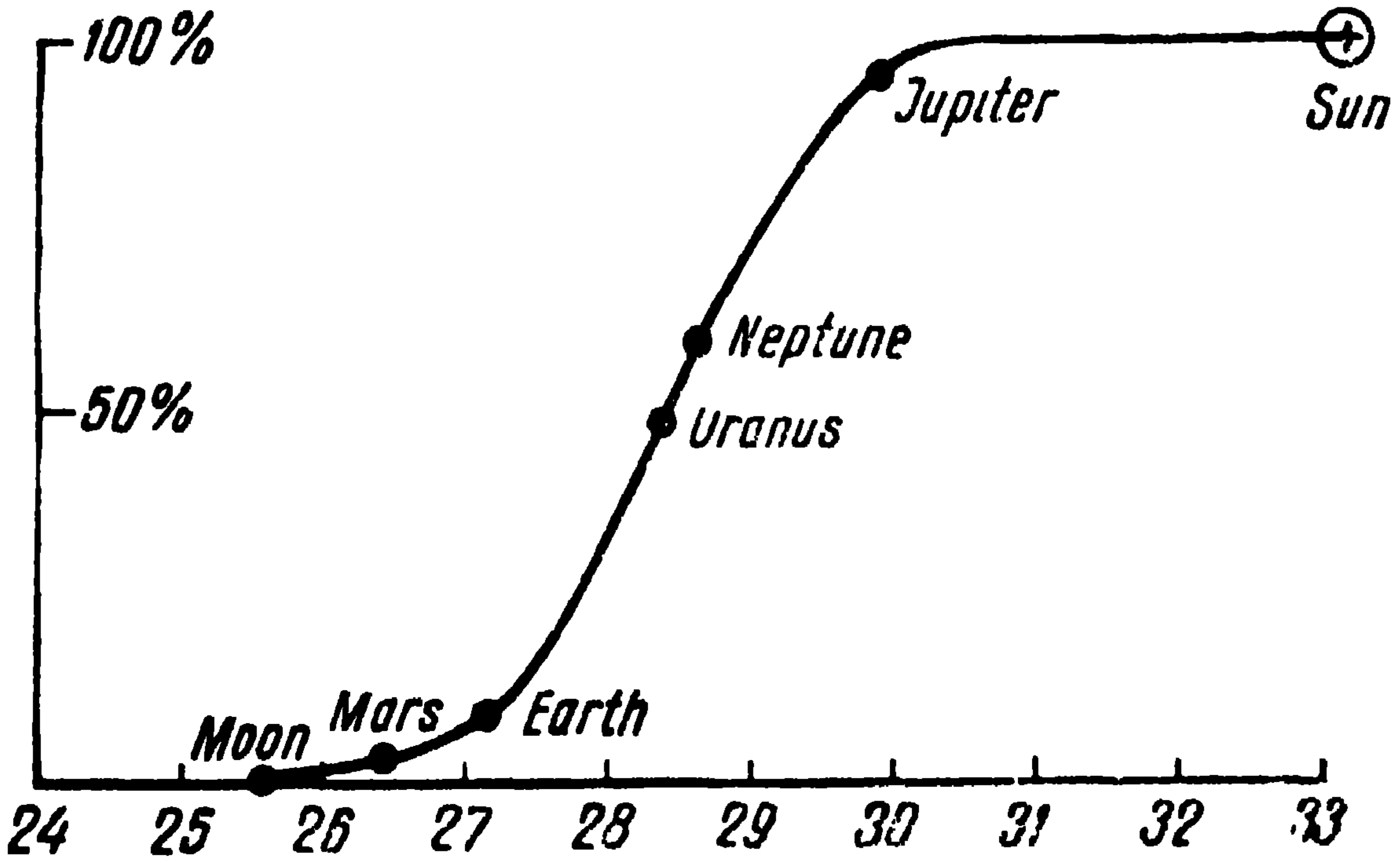

Fig. 28. Diagram of approximate abundance of hydrogen depending on the planetary mass

There must be enough hydrogen on a planet to form large masses of water which would ensure a vigorous water cycle in nature and disperse various elements over the surface of the planet. It was precisely as a result of such a water cycle on the Earth during long geological epochs that the waters of the oceans in which life originated were enriched by all elements and their compounds necessary for building protein molecules. Life cannot originate and develop on a celestial body where there is hardly any water cycle. Mars is one of the planets where life is hardly possible because the shortage of water must have caused the elements to disperse much more slowly than they did on the Earth.

Thus, the study of the chemical composition of the planets of our solar system leads us to believe that all the planets must have formed from the same medium as the Sun and, probably, at the same time, but that the less massive planets must have lost part of their original light gases. The Earth, in particular, has fully lost its original atmosphere and at the same time a considerable part of its original mass. This is precisely why the present-day composition of the Earth differs so greatly from the normal chemical composition peculiar to the Universe.

The question may be asked as to what the temperature conditions were at the initial stage in the existence of the planetary condensations, during the period of their formation. Jupiter, which has nearly fully retained the original abundance of elements, cannot be indicative in this respect. Uranus, for example, where the loss of light elements has definitely begun but has not gone very far as yet is more characteristic.

The temperature of the Earth, considerably closer to the Sun at an early stage in its development, must have been much higher regardless of the absorption of solar radiation by the original proto-planetary cloud. It goes without saying that the Earth, like the other planets of the terrestrial type, must have lost from the very outset most of its hydrogen and along with it the other elements which remained in a gaseous state and did not form any compounds with other more refractory elements.

We may, thus, conclude that the hydrogen was lost, most probably, during the period of the planet's formation. It was a very rapid process, which ended at the very earliest stage in the life of the planet as a cosmic body. We, therefore, have no reason to believe that any planet is slowly and gradually losing any hydrogen or, especially, its compounds. In particular we have no reasons to believe that in the distant past there was more water on Mars and that the conditions on it were more suitable for life than they are now. Similarly, there are no indications that during the long geological epochs the total quantity of water has changed in the oceans of the Earth to any appreciable extent. On the contrary, geological and paleontological data indicate that the total surface occupied by oceans is increasing as tectonic activity on the Earth is decreasing. This process resulted in the disappearance of certain continents, for example, Gondwana, which formerly connected Asia with Australia, and, relatively recently, Atlantis, from which only the islands of the Aegean Archipelago have, apparently, remained.

In all probability, the total mass of water on the Earth has suffered no change in the last several hundred million years. However, the planets differ in their ability to retain their gaseous atmospheres, and some dissipation of the light elements into space is still possible today. But this process is extremely slow and we shall dwell on it later.

Let us now consider the peculiarities of the planets of the solar system and try to decide to what extent these peculiarities must be characteristic of the other planetary systems. We have observed that a planet with a sufficiently large mass has an identical chemical composition with its central luminary. Generally, as we have already mentioned, the difference between a star and a planet is only in the mass, only in the fact that the star, owing to sufficient pressure and temperature in its central regions is capable of radiating atomic energy; planets do not have this ability. But if its mass increases to at least 1/20-1/25 of the solar mass the planet will inevitably become a luminescent body—a star. In general, there is every reason to believe that the process of stars' planet formation is extraordinarily widespread in nature.

It can be very easily shown that the formation of a single star, even a rapidly rotating giant, from a sufficiently condensed gas and dust cloud would require an extremely precise compensation of angular momenta of individual particles making up the cloud. The final result of such condensation should far more frequently be the simultaneous formation of several stars, among which the initial reserve of angular momentum is distributed. In addition, the angular momentum is partly connected with the intermediate medium which is also considerably condensed and cannot form part of the star without upsetting its gravitational equilibrium. Multiple systems, rather than individual stars, like our Sun, are, therefore, usually formed in the Galaxy. Thus, we must consider that several thousand million years ago our Sun formed like other stars from some local condensation in a gas and dust medium. Compared with other analogous condensations this condensation had a small reserve of angular momentum and this resulted in the formation of only one star—the Sun. Nevertheless, a considerable part of the mass of the original condensation could not concentrate in one body because of the excessive angular momentum and, therefore, remained outside arranging itself in its equatorial plane.

Thus, all the data concerning the process of star formation show that the primary Sun must have been surrounded by a gas and dust medium in the form of a sufficiently dense diffuse cloud compressed and condensed towards the centre. The planets existing today have formed from this cloud and have retained part of its angular momentum. This gas and dust cloud of the same composition, of course, as the original Sun could, additionally, constantly receive gas streams due to the intensive corpuscular radiation occurring at this early stage also chiefly in the equatorial plane.

If the mean density of the primary cloud was not very small local condensations capable of withstanding the disintegrating tidal action of the central body must have arisen in it due to the inevitable local "overfalls" of densities. If the density of such a cloud, remaining outside the primary condensation, were not sufficient it would inevitably disperse in space after the final formation of the star as a luminescent body and the separate dust particles, which formed part of it, could gradually fall on the central body as a result of radiation hindrance.

Thus, the primary dust and gas cloud and the condensations arising in it must have been sufficiently dense from the very outset. Stable against the disintegrating tidal action of the Sun these condensations continued their independent existence moving in a more rarefied medium and adding the particles of this medium to its own mass.

This process of the gradual growth of the formed condensations may, generally speaking, be imagined in various ways. We saw above that the temperature in such condensation must have been low. The original cloud must have cooled through the lowering of the temperature of the gas molecules in their constant collisions with the cold dust particles. Later, as the cloud condensed this low temperature must have been maintained because the cloud intensively absorbed short-wave radiation but continued to filter its own low-temperature radiation. But its temperature could under no circumstances drop below that of the dust matter in the inter-stellar space far from actinic stars. This determines the lower possible limit of temperature of the proto-planet cloud which is estimated at 10-20° abs. At this temperature hydrogen even in a molecular state, and especially helium, must have remained in a gaseous state.

The motion in a resisting medium and the averaging of the angular momenta of the meeting particles result in the fact that the orbits of the condensations hardly differ from circular orbits from the very outset. Besides, owing to the flattened form of the initial cloud they arrange themselves approximately in the same plane which hardly differs from that of the solar equator. On the basis of these considerations it is not hard to deduce all the basic properties of the solar system if we only know the approximate distribution of the planetary masses. In part, we can show the precise law of planetary distances and explain why the planets rotate on their axes exactly with the period of rotation now observed. For this we must, primarily, find the mathematical expression of the fact that the formed planet is stable not only as regards the Sun, i. e., is capable of resisting its tidal action, but also as regards the closest planet, i. e., can also withstand its additional tidal action. In other words, we must find the expression for the law of planetary distribution proceeding from the condition that the planets "hinder" each other as little as possible.

In all probability the distant planets must have formed first while the formation of the larger planets must have occurred ever closer to the Sun. Naturally, Pluto, the planet with a small mass and the farthest from the Sun, must have formed first. The formation of Neptune, the next planet, had to satisfy the requirements of tidal stability as regards the Sun as well as the already existing Pluto. Hence, Neptune could have formed only at a sufficiently "safe" distance from this planet and this determined the first interval between the planetary distances. Uranus, the next planet, could have formed only far enough away from Neptune, etc. It is, therefore, clear why the intervals between the orbits of such massive planets as Jupiter and Saturn are the greatest in the solar system; for the external and internal regions of the solar system these intervals diminish.

Mercury, the closest planet to the Sun, and Pluto, the farthest from the Sun, are the smallest of the large planets. It should be mentioned, however, that the law of planetary distances for all planets without exception is based on purely physical considerations with the assumption that the original planets, or, more exactly, the planetary condensations were of the same chemical composition, i. e., they were composed on the average from the same elements, mainly hydrogen. Subsequently, the very massive planets, such as Jupiter, for example, considerably removed from the Sun, almost fully retained their original composition and are now composed mainly of hydrogen and partly of helium with a big admixture of heavier elements. The planets closer to the Sun and less massive from the very beginning have not retained their original composition and are now only nuclei of the original planets composed of heavier elements.

Thus, under the indicated condition of a similar chemical composition of all planets of the solar system we can get the following values of their distances from the Sun based on a somewhat evened-out distribution of the masses:

Planets	Distance from the Sun (in radii of the Earth's orbit)	
	observed	calculated
Mercury	0.39	0.43
Venus	0.72	0.64
Earth	1.00	0.98
Mars	1.52	1.55
Asteroids	—	2.65
Jupiter	5.2	5.2
Saturn	9.5	11.0
Uranus	19.2	19.6
Neptune	30	29
Pluto	39	40

Apparently, the assigned values of the planetary masses make it possible to find the distances between the planets and the Sun. If the planetary masses were different the distribution of the planets in the general plane of the planetary motions would differ from the existing distribution.

It is impossible to determine the planetary masses purely theoretically. A possibility of such calculation would mean that all stars must have exactly the same planetary systems, which is, of course, incongruous. It can only be said in general that the conditions most favourable to the formation of massive planets are created in the central part of the original planetary cloud poorly heated by solar radiation.

To determine the period of rotation of a planet with a given mass and distance from the Sun we must take it that the formed planetary condensation included the mass not only in one limited area of the original nebula, but nearly all along the circumference of its orbit and that the angular velocities of rotation around the centre were considerably equalized due to the interaction of the particles among themselves and, particularly, owing to their intermixing. We thus get a very simple expression which shows that the quantity of rotation of a forming planet is proportional to the mass multiplied by the square root of its distance from the Sun.

Here, too, we get a close analogy with the stars. As a matter of fact it is precisely the massive stars that have the greatest rotary reserve and rotate on their axes with the greatest speed. It also turns out that the more massive planets in the solar system must rotate faster, and this is what we actually observe.

The conception of the origin of the solar system presented here and based on the analysis of its general regularities makes it possible to explain all its main peculiarities. This conception was first voiced in the U.S.S.R. in 1919, though it was insufficiently elaborated for lack of precise initial data.

It follows from this theory that the origin of the planets is a definite and regular process widespread in nature and that the planets have formed from substance closely connected with the primary Sun without any interference of outside forces. It is now being definitely ascertained that the origin of the planets is connected with the formation of stars near which they find themselves and that it is one of the aspects of the general process of formation of stars and stellar systems.

The advanced minds of humanity have always been interested in the problem of the origin of the solar system. The first scientific hypothesis of the development of stellar systems and planets was advanced as early as 1755 by the German philosopher Immanuel Kant, who proceeded from the idea of original chaos composed of separate solid particles similar to meteorites. This hypothesis, for the first time considering the process of development of the cosmic bodies, which were until then believed to have been immutable from the very moment of their supposed "creation," was of great progressive importance for its epoch and was highly appraised by F. Engels.

At the end of the 18th century the famous mathematician and astronomer Laplace expressed a more private but better elaborated hypothesis of the origin of the solar system from an original gaseous nebula with a very considerable central condensation. According to this hypothesis the nebula rotated on its axis and gradually cooled and contracted as a result of which successive rings of gas split off and later formed secondary condensations—the future planets. This, so-called, Nebular Hypothesis, was generally recognized in the 19th century. It has now been established that in its original form this hypothesis is incompetent and cannot explain all the regularities observed in the solar system.

The hypothesis of Jeans, which replaced it, persisted for a couple of decades because at that time there were as yet no ideas of the evolution of the Sun and stars and it was believed that even in the epoch of the origin of planets the Sun had approximately the same properties it has now. According to this hypothesis the planets were formed from a filament drawn out of the Sun by a closely passing star. This idea inevitably leads to the ideologically erroneous conclusion about the exceptionalism of the solar system in the Universe. Besides, Jeans' hypothesis is unable to explain the basic peculiarities of the solar system either.

Many different considerations were expressed after the collapse of Jeans' hypothesis; they were frequently ingenious conjectures and suppositions, but without sufficient grounding.

The work done in the last ten years in the Soviet Union has greatly contributed to the development of cosmogony. In his numerous investigations Academician O. Y. Shmidt developed the idea that the Sun had seized part of a dust meteor cloud and regarded the mechanism of its transformation into separate condensations—the future planets—as a result of mutual collisions and "adhesions" of the dust particles. Proceeding from these considerations and accepting some simplifying hypotheses he deduced mathematically the basic regularities observed in the solar system. A. Lebedinsky and L. Gurevich considered an analogous problem of the formation of the planets from an initial diffuse medium by assuming that the Sun was originally surrounded by a rather dense gas and dust nebula which soon acquired the shape of a very flat disk. In this disk, owing to its low temperature, the entire gas "froze out" by settling on its dust particles. The break up of the dust disk, which had thus originated, into separate massive bodies with regular intervals between them is connected, according to the authors, with the motion of the particles along elliptic orbits with a certain degree of elongation. The idea of a direct mechanical interaction of the particles in the initial gas and dust medium is also advanced in this case.

Then V. Krat supposed the existence of a primary diffuse cloud, mainly of a gaseous composition, of which only a very small part formed the planets, while the remaining mass was dispersed in space as was also a considerable part of the solar mass.

Thus, leaving out the details of the process of the origin of the solar system, nobody doubts any longer that the planets formed from some sufficiently dense gas and dust medium which originally surrounded the Sun. As regards the *origin of this cloud there has been no agreement* until recently and this question was not given any consideration at all. But today the cosmogony of the planetary system stands on a solid foundation owing to the recently obtained results concerning the process of formation of stars and, consequently, the Sun. The initial conditions of the origin of planets are becoming sufficiently clear and must no longer serve as the subject for ungrounded conjectures and scientific fantasy.

We have seen that the fully formed stars possessing normal properties are still immersed in the general medium of gaseous matter. The process of star formation now taking place in some regions of the Galaxy vividly shows that during the first epochs of its existence the Sun was a massive and rapidly rotating star surrounded by the same gas and dust medium from which it had itself originated. It was from this medium, which could not unite into one central body because of its excessively rapid rotation, that the present-day planets had formed.

Only those of the many forming condensations "survived" and gave rise to planets, which were subjected to the least perturbations. The use of this simple principle of least interference makes it possible to find the correct distribution of the planets according to the distance from the Sun and explain the characteristic features of the systems of satellites.

But the planets sufficiently massive to be fit for the development of life cannot revolve around their Sun along orbits close to each other. The intervals between the orbits of neighbouring planets must necessarily be sufficiently large and the planets receiving radiation from the Sun must, therefore, find themselves under absolutely different temperature conditions. The number of planets in one and the same system may be sufficiently large, about ten, but only very few of them may have the conditions favouring the origin and maintenance of life.

Chapter IV

GENERAL CONSIDERATIONS OF THE STRUCTURE AND EVOLUTION OF THE ATMOSPHERES OF THE EARTH AND PLANETS

It is well known that all gases tend to take up the greatest possible volume due to the haphazard and independent motions of their molecules. The Earth and some other planets, therefore, have sufficiently dense gaseous atmospheres only because gravity prevents their dispersion in space. At the same time all gases at a certain temperature have a more or less considerable reserve of kinetic energy. The higher the temperature the greater the ability of the gas to expand, since its molecules move at a greater speed. At a temperature of absolute zero the gas molecules would lose all motion and would have to fall on the surface of the planet. Due to the continuous and quite elastic collisions with each other a constant redistribution of velocities occurs among the individual molecules, but in general the mean velocity of the molecules of a given gas is represented by the following simple formula:

$$Vm=\sqrt{\frac{3kT}{\mu}},$$

where T is the absolute temperature, μ is the molecular weight and k is some physical constant determined by Boltzmann and bearing his name.

According to this formula we have, for example, the following mean velocities of molecules (in m/sec) for different gases at a temperature of 0°C or 273° abs.

Atomic Hydrogen	Molecular Hydrogen	Nitrogen	Oxygen	Carbon Dioxide	Water Steam
H	H_2	N_2	O_2	CO_2	H_2O
2,600	1,839	493	461	392	708

Maxwell has shown that as a result of the constant collisions among the molecules of the same gas the velocities are distributed on both sides of the aforesaid mean magnitude so that along with rapidly moving molecules there are also slowly moving ones. The relative number of molecules with a certain velocity v is represented by the following expression:

$$N_{(v)} = CN_e^{-\frac{-mv^2}{2kT}}{}_{v^2}$$

where C is the constant, depending on the mass of the molecule and the temperature of the gas. This expression may be represented by the following diagram (see fig. 29).

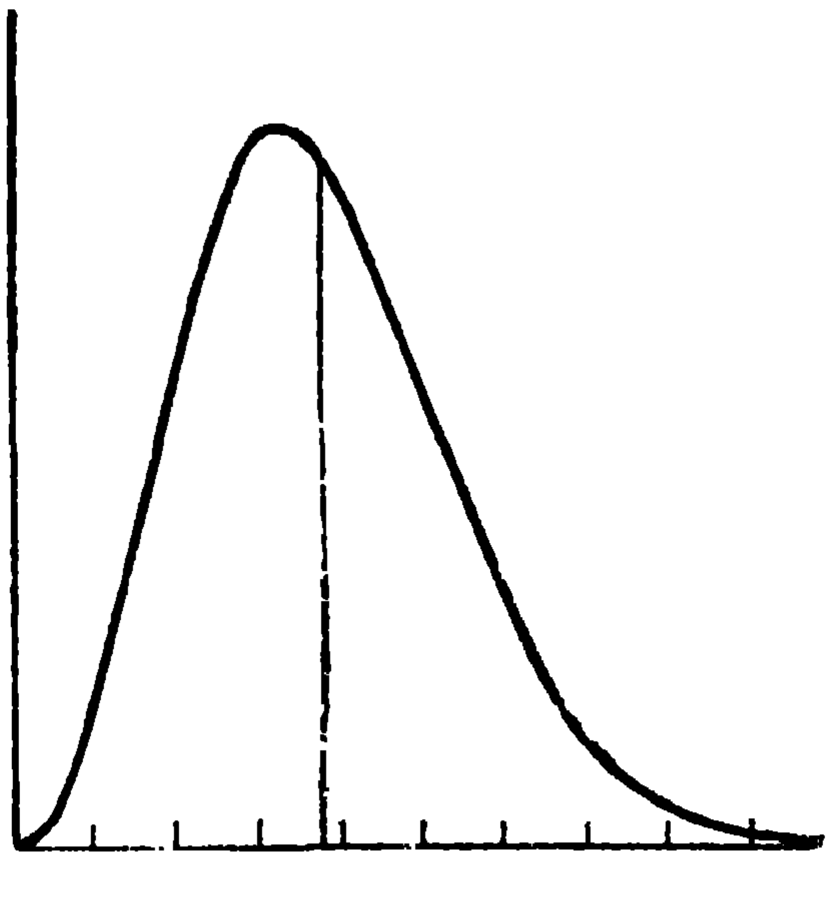

Fig. 29. Maxwell's distribution of velocities

This distribution of Maxwell's is inevitably established in a very short time in the case of a sufficiently dense gas, but may not take place at all if the gas is very rare, in which case the molecules collide very seldom and the free run, i.e., the interval between the successive collisions, becomes comparable with the total volume of the given gas. In the real planetary atmospheres the condition of sufficiently frequent collisions is always observed and, therefore, the distribution of the velocities of individual molecules and their mean velocity are fully determined by the temperature of the medium and the molecular weight of the gas.

If the velocity of a given molecule is sufficiently high it may under certain conditions avoid the gravitational influence of a planet and escape into inter-planetary space. This is the process of dissipation which in some measure occurs constantly and leads to a gradual diminution of the masses of gas shells around the planets. We shall now consider this dissipation in greater detail and discuss its possible effects during the existence of a planet.

We shall begin with the fact that any body near the Earth's surface is subject to acceleration of gravity equal to 9.8 m/sec and that in the very first second of free fall it passes 4.9 metres towards the centre of the Earth regardless of the direction of its motion. Let us assume that a body was ejected in a horizontal direction; in this case its trajectory will curve in the direction of the Earth's surface and, as we can easily figure out, this curving at the velocity of motion of 8 km will precisely correspond to the curvature of the globe. Consequently, a body ejected at this velocity (discounting the resistance of the atmosphere) cannot fall to the Earth and will revolve about it along a circular orbit. If the body is ejected with twice the force and, hence, if it has a velocity of 11.3 km/sec it will lose all connection with the Earth and will move away from it infinitely. This is the so-called velocity of escape which equals the parabolic velocity with respect to the given planet. It is determined by a simple mathematical expression and can be easily calculated for any planet:

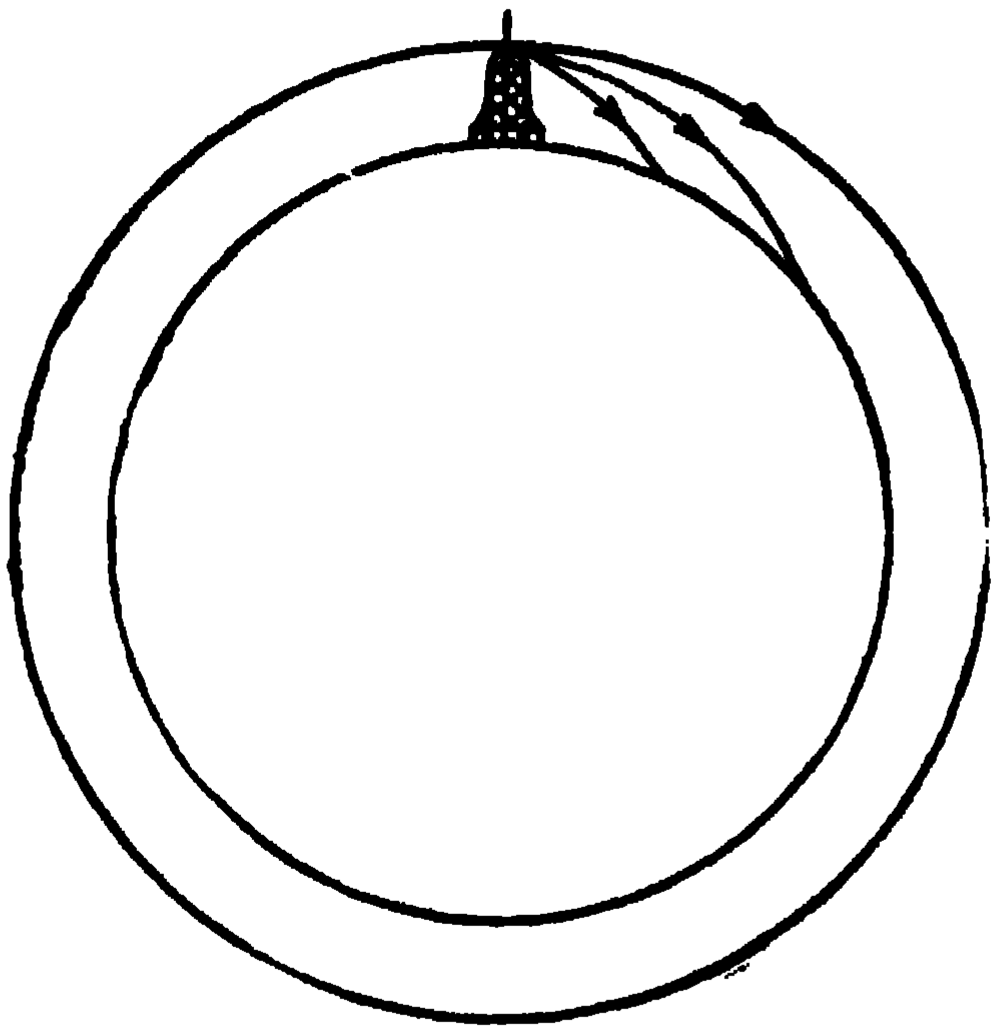

Fig. 30. Distortion of the trajectory of a horizontally moving body

$$V_{escape.} = \sqrt{\frac{2GM}{R}} = 11.3\sqrt{\frac{M}{R}} \text{ km/sec},$$

where *M* is the mass of a planet and *R* is its radius expressed in the units of mass and radius of the Earth.

It is, thus, obvious that any molecule, which moves at a greater than parabolic velocity with respect to the Earth, will inevitably escape into cosmic space if it does not encounter some obstacle, as, for example, other molecules.

This escape of gas into space may, thus, actually occur only in the highest atmospheric layers where the gas is rare, where the length of the free run becomes comparable to the radius of the planet itself and where the molecules do not, therefore, necessarily encounter other molecules. Gradually rising higher above the surface of the planet we at last find, primarily in the direction of the zenith, that the molecules do not fully screen the sky, the voids gradually appear between them and that these voids expand the higher we rise. For the Earth's atmosphere such voids near the zenith, the so-called cone of escape, begin at the altitude of 400-500 kilometres above the surface of the Earth. Thus, it is only here that the conditions necessary for the dissipation of gases into cosmic space are on hand. For such dissipation actually to occur, i. e., for a molecule, headed for the cone of escape, never to return it also requires, as we have already said, a velocity higher than the limit parabolic speed, which for the Earth equals 11.3 km/sec. Theoretically each gas, which is subject to Maxwell's distribution of velocities, will have a certain number of molecules with such high velocities, but the relative number of such molecules very rapidly diminishes as the molecular weight increases or the temperature lowers.

Hence, if the mean molecular velocity is considerably lower than the parabolic, the process of escape will occur extraordinarily slowly because only a very small part of all the molecules can participate in it. At the same time, after the fastest molecules escape into space, Maxwell's distribution will, apparently, be upset and it will be some time before the mutual collisions of the remaining molecules restore it. But then a new similar part of molecules with high velocities will result and they will again be able to escape into space. If only a very small part of the entire atmospheric mass participates in the process of dissipation it may be assumed that ever new molecules with Maxwell's distribution of velocities are constantly fed from below to the rarefied atmospheric layers and on the basis of this the speed with which this process occurs can be calculated.

Jeans was the first to make such computations. He has shown that the length of time the atmosphere of a given planet can exist greatly depends on the mean molecular velocity of gas, namely, if the velocity of escape is four times that of the mean molecular velocity the atmosphere will almost fully disperse in space in 50,000 years, i. e., in a very short geological period of time; if the aforesaid ratio equals 4 1/2 the atmosphere will last 30 million years; and, finally, if the velocity of escape is five times as great as the mean molecular velocity full dissipation of the atmosphere will require the enormous period of 25,000 million years, which considerably exceeds the age of the Earth and the planets. On the basis of these calculations we will, thus, assume that the criterion of full preservation of the atmosphere is a value of the mean molecular velocity which must constitute no more than 0.2 of the velocity of escape.

This mean molecular velocity depends for each gas, as has been shown above, on the temperature of the planet, while the temperature is determined, everything else being equal, by the distance of the planet from the Sun. For this reason the mean molecular velocity generally diminishes in proportion to the distance from the Sun:

$$r^{-\frac{1}{4}},$$

where r is the radius of the planet's orbit.

Owing to this the distant planets are in much better conditions for retaining their atmospheres than the ones closer to the Sun. It may be assumed that the ability of a planet to retain its atmosphere is characterized by the magnitude:

$$V_{escape}\, r^{-\frac{1}{4}} .$$

For the different planets of our solar system we obtain the following figures:

Planets	v_{escape} (km/sec)	$v_{escape} r^{-1/4}$
Mercury	3.8	3.0
Venus	10.4	9.6
Earth	11.3	11.3
Mars	5.1	5.7
Jupiter	61	92
Saturn	36.7	64
Uranus	21.6	45
Neptune	23.8	56
Pluto	11	27

Satellites	v_{escape} (km/sec)	$v_{escape} r^{-1/4}$
Moon	2.4	2.4
Triton (Neptune's satellite) . .	2.8	6.6
Titan (Saturn's satellite) . . .	2.8	5.0
Jupiter's satellites I	2.4	3.7
II	2.1	3.1
III	2.9	4.4
IV	2.4	3.6

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As has been pointed out, the magnitude, V_{escape} , used in this table, characterizes the ability of a planet to retain its atmosphere under conditions of its thermal equilibrium and in some measure allows a comparison between the different planets and their satellites.

According to this table, we can say, for example, that under the existing temperature conditions the Earth can easily retain any gas, even the lightest—hydrogen, since its mean molecular velocity of 1.8 km/sec is much lower than the 20 per cent of the velocity of escape.

Contrariwise, our Moon should have lost all its gases. Only those, whose molecular weight exceeds 60, could have remained on the Moon. Of these gases sulphur dioxide SO_2 with a molecular weight of 64.1 possibly exists on the Moon since it is usually connected with volcanic activity. Very small amounts of such a gas with an equivalent thickness of only 1 mm in the atmosphere are capable of producing sharp lines of absorption in the region of the spectrum 3,000-3,100Å. However, Kuiper's searches for such lines of absorption in the spectrum of the moon proved fruitless. It is, therefore, unreasonable to expect any lighter gases on the Moon.

It should be noted, however, that the real conditions of the atmosphere's dissipation into space are much more complex than represented in the above table. In the first place, the temperature of the layer of escape, which for the Earth lies at the altitude of 400-500 kilometres, is in no way determined by the temperature of the Earth's surface. At different altitudes of the Earth's atmosphere the temperature in large measure depends on the chemical composition of the atmosphere and on the interaction of the molecules of various gases with high-frequency quanta of solar radiation. It is well known that beginning at an altitude of approximately 100 kilometres the oxygen of the Earth's atmosphere exists in atoms, rather than in molecules, and in the extremely rarefied air and, consequently, relatively rare encounter with other atoms and molecules, is able to retain its state of excitation only under special conditions. An excited atom of oxygen left to itself under these conditions may give up its energy charge to any other atom it collides with, in which case the latter increases its kinetic energy with the resultant rise in the atmosphere's temperature.

Thus, the temperature in the higher layers of our atmosphere may rise considerably higher than is possible on the very surface of the Earth, in this way facilitating the dissipation of gas, which happens to take place precisely at those altitudes. Observations show that the temperature of the Earth's atmosphere reaches its minimum at an altitude of about 80 kilometres, then continuously rises and at very high altitudes may reach even several hundred degrees C. This may, in all probability, explain the fact that the lightest gases—hydrogen and helium—absolutely cannot exist in a free state on the Earth. There is extremely little helium in the free atmosphere, namely, only about five-millionths by volume at the Earth's surface, which is much less than could be expected considering the constant emission of this gas as a result of radio-activity during the long geological epochs.

All the foregoing warrants the following conclusion: the largest planets of the solar system can retain all gases in their present state. The Earth is losing free hydrogen and helium, apparently, because of the presence of atomic oxygen at high altitudes, but could retain even these gases under the temperature conditions prevailing on its surface. Venus is approximately in the same state. Mars can easily retain an atmosphere of molecular oxygen and nitrogen, and, especially, of carbon dioxide, but free hydrogen should have very rapidly dissipated into space and for this reason, as it may be assumed, even its compounds with other elements, primarily with oxygen, cannot abound on this planet.

On Mercury there can be no air shell at all. Owing to their small mass all satellites of the planets, save Titan, the most massive satellite of Saturn, which in addition has a very low temperature, are in very unfavourable conditions for retaining air mantles. The more so must the numerous asteroids, which revolve mainly in the interval between the orbits of Mars and Jupiter, be deprived of atmospheres.

The foregoing considerations are based on the present-day properties of the planets, particularly, the Earth. They very well define the conditions under which the already existing atmospheres are retained and point out that an atmosphere composed of a definite gas is either fully retained through geological epochs or is dissipated. As a matter of fact a very small increase in the mean molecular velocity suffices to reduce the period of possible dissipation manyfold.

These considerations, however, do not directly pertain to the problem of the initial conditions in which the planet found itself when it had already formed as a fully solid body. What was the temperature of its surface at the time? Was the planet a fiery-liquid body as most of the geologists very recently believed, and partly still do, or was the planetary mass originally absolutely cold and heating only gradually because of the radio-active disintegration particularly intensive several thousand million years ago? Can we assume that the negligible content of inert gases with a big molecular weight—neon, argon, crypton and xenon—in the present-day atmosphere testifies to the high temperature of the primary Earth? We have already offered arguments against such a conclusion. The almost complete absence of these gases was, apparently, conditioned by the enormous escape of hydrogen which carried away with it all the other elements of the original atmosphere.

The present state of the Earth was, in all probability, determined by the conditions of its formation from the primary condensation during the early stages of which the hydrogen and the light elements, in general, escaped. From the point of view of the theory of planetary origin from a primary gas and dust cloud, which surrounded the solar condensation, a high temperature on the primary Earth is out of question. On the contrary, formation of stable condensations was possible, as we have seen from the foregoing, only at a very low temperature of the gas and dust cloud. Subsequently, as the condensations grew denser the temperature rose, which, in all probability, determined the escape of hydrogen into space except the quantity that happened to form stable compounds with other elements, chiefly with oxygen.

As a result the heavier and refractory elements with a certain amount of gases occluded in them remained and formed the present Earth. The various compounds inside the Earth were determined mainly by conditions of high pressure and occurred chiefly in the direction of lesser equivalent volume. Thus, for example, since a usual iron molecule occupies a much smaller equivalent volume than the compound of iron and oxygen Fe_2O_3 conditions favouring disruption of the molecular bonds and the isolation of pure iron were created in the deep interior of the Earth even without any high temperature. All the chemical reactions under the tremendous pressures inside the Earth must have occurred in accordance with this principle.

According to Parson's calculations the pressure necessary for the dissociation of ferric oxide constitutes 570,000 kg/cm^2, which corresponds to a depth of approximately 1,400 kilometres. A greater pressure, about one million kg/cm^2, must disrupt the electronic shells of the atoms, while any substance acquires electro-conductive "metallic" properties and at the same time considerably increases its specific weight, which is precisely what occurred in the central core of the Earth. A similar "metallic" dense core cannot develop in planets with a small mass and a relatively small pressure in the centre.

Thus, from the point of view of the observed stratification of the globe there is no reason to believe that the temperature could have been very high in it from the very beginning and that considerable convectional currents and movements of substance of different specific weight could have taken place inside the Earth. On the contrary, this stratification is explained mainly by the effect of pressure. Nevertheless the internal body of the Earth has a substantial reserve of energy and is not in a quiet state even today. Mountains repeatedly rose and were later evened out again by water and wind erosion many times during the evolution of our planet. There were four large cycles of mountain formation in Europe, namely before the Cambrian, during the Silurian, at the end of the Carboniferous and in the Tertiary periods with 5 or 6 small ones in between. According to Holmes there was a total of 20 cycles of mountain-formation in Europe, including the small ones, and approximately as many in America. The rise of mountains as a result of folds was followed by long periods of denudation, erosion and levelling.

Thus, since the earliest epochs of the existence of the Earth traceable by geological data the Earth's crust has been in motion which now intensified and now died down. How deep in the Earth does the prime cause of these motions lie? It may be asserted that the depth by far exceeds the thickness of the Earth's crust and corresponds to the deep interior of the Earth. Such assertions are warranted by the astronomical investigations in the changes of the length of day.

The studies of Jeffreys, de Sitter, Braun, Clemence, et al., have shown that the rotation of the Earth gradually slows down mainly under the action of the tidal forces of the Moon and the Sun. This slowing down is not uniform, however. The deviations in the length of the day are expressed only in thousandths of a second. This necessitates an alteration in the relative moments of inertia of about 10^{-9}. The greatest relative change in the moment of inertia occurred in 1897 and constituted 4×10^{-8}. These changes occur rapidly, the entire change lasting but few months, 2-3 years at most. The dates of seven similar changes in the velocity of the rotation of the Earth, and, hence, in the moment of its inertia, can be pointed out since 1667. This important phenomenon needs an explanation.

If the entire mass of the Earth had taken part in the deformation of 1897 the radius of the Earth should have changed by only 13 cm. Contrariwise, if we assume, according to Braun, that the change occurred only in the surface layer 80 km thick while the rest of the Earth's mass had not changed at all, the radial displacement along the entire spherical surface would have constituted 5-6 m. It is absolutely impossible, however, to assume that these leaps simultaneously affect the entire surface of the Earth. It is much more natural to suppose that they occur as a result of local deformations, for example, under individual continents. In this case they should be much greater. With a layer 80 km thick the local radial displacements should, perhaps, extend over hundreds of metres. This has never been observed. It necessarily follows that considerable masses of the Earth take part in the radial displacements and that the seats of these displacements arise at a depth of many hundreds of kilometres. The seats of hypogene earthquakes precisely correspond to this.

These hypogene seats of earthquakes were discovered, for example, by A. Zavaritsky near Kamchatka, under the Asian Continent, at a depth of about 600 kilometres. The centres of volcanism are located in the same plane of rupture at an angle of 30° to the surface of the Earth and at a depth of 150 km. Similar hypogene seats of tectonic dislocations have been discovered in many regions of the globe.

Thus, all the similar data indicate that the main mass of the Earth is not in a state of thermal equilibrium as would be the case with a cold body surrounded by a radio-active radiating shell.

On the contrary, it turns out that powerful processes take place at great depths, that they are reflected on the surface and shake the whole planet.

Hence, there are no reasons to believe that the primary Earth was an absolutely cold body though it was surely not in a burning hot state. This idea of the relatively high temperature of the Earth, which at the deepest layers amounts to 3,000°C, according to seismic data, even today, is also confirmed by the distribution of radio-active elements on the Earth.

It is known that uranium, the heaviest element, concentrates mainly in the acid rocks, basalts, but the basic rocks have relatively very little of it. It is widespread in granites, enriches water solutions and is, therefore, found in all sedimentary layers. The deeper in the Earth the less uranium. The old lavas erupted from great depths contain but negligible quantities of it, the younger lavas—much greater quantities. There is approximately 100 times as little of it in meteorites as in basalts.

It is but natural to assume that whatever the formation of the Earth, in the beginning the radio-active substances must have been distributed in it evenly. In the process of the further evolution of the Earth these radio-active substances, despite their extremely high atomic weight, separated themselves from the central and intermediate parts of the Earth and formed a relatively thin surface layer concentrating mainly on the continents. This process of differentiation is, apparently, connected with the poor ability of uranium to form compounds with other elements but it must at the same time also be determined by certain intensive circulation of substance between the deep and surface parts of the Earth. These currents cannot take place without sufficiently high temperature. Otherwise, with the pressure of hundreds of thousands and even millions of atmospheres and with a correspondingly tremendous viscosity, so complete an enrichment of the upper layers by uranium at the expense of the main mass of the globe would have been impossible. We can add to this that the modern ideas of the nature of terrestrial magnetism also spring from the supposition that there are intensive circulating currents in the internal liquid core of the Earth.

We must, thus, apparently, assume that the Earth has formed from a sufficiently cold proto-planetary cloud and was originally one of its condensations. In the process of compression this condensation must have become heated which made for the loss of the light gases, hydrogen in the first place. Oxygen persisted in considerable quantities due to its enormous chemical affinity in combinations with hydrogen, carbon and many other elements. During the formation of the hard crust and later in the process of numerous and intensive volcanic eruptions the Earth received a great deal of water vapour, carbon dioxide and other gases which separated themselves from the liquid magma. These newly separated gases formed a secondary gas shell about the Earth. This shell is not massive; it constitutes somewhat less than one-millionth of the mass of the Earth.

This secondary atmosphere of the Earth had no free oxygen and, hence, no ozone at all. It is now generally recognized that free oxygen in the Earth's atmosphere is the result of the activity of green plants and seaweeds, namely, the product of photosynthesis. Under the action of solar radiation carbon dioxide split over a period of many millions of years into carbon and oxygen. Carbon was used in the building-up of the organic substance proper which was in large measure buried in the interior of the Earth in the shape of coal, peat and oil, while oxygen formed part of the atmosphere. The presence of free oxygen in the atmosphere of the planet is, thus, direct and incontestable proof that the planet has a biosphere capable of transforming the composition of the atmosphere and even the properties of the surface of the planet.

We, thus, see that the atmosphere of the Earth has gone through a long course of evolutionary development. This evolution is very closely connected with the origin and development of life. Knowledge of the original conditions under which our Earth existed is of great importance to a better understanding of the origin and development of life on the Earth and on other planets.

Chapter V

PHYSICAL CONDITIONS AND POSSIBILITIES OF LIFE ON THE MOON

Soon after the invention of the telescope and its use in investigating the celestial bodies it became clear that the nature of the Moon sharply differs from that of the Earth, that there is no water, clouds, air nor, generally, any of the most necessary conditions for the existence of life on it. As far back as 250 years ago in his book *Entretiens sur la pluralité des mondes* Fontenelle wrote the following concerning the nature of the Moon:

"... The Sun raises neither smoke nor steam above the Moon. It must be a heap of wild rocks and marbles which never emit any vapours. It is so natural for them to be where there is water that where there are no vapours there cannot be any water. Who are the inhabitants of those wild rocks that cannot produce anything and the land that has no waters?" Thus, it was perfectly clear to Fontenelle that there was no water or air on the Moon. Hence, it was quite reasonable to conclude that there could be no forms of life, at least no highly organized forms. But the desire to people every cosmic body with living and even thinking beings was so great that even sober scientific research could not resist it. The tendency to people the Moon with some forms of life at all costs has continued to-date.

The proponents of the idea of life on the Moon in the beginning of the 19th century were the well-known astronomers Schröter, who made extensive observations of the Moon, and Herschel. Both of them enjoyed great scientific authority. In 1822 the German astronomer Gruithuisen, the founder of the meteorite theory of the origin of lunar craters, declared he had discovered a lunar city on the border of Sinus Media near the central lunar disk. Gruithuisen even gave a detailed description of this imaginary city. Only later did the investigators of the Moon Beer and Mädler show that it had all been no more than fancy, a desire to find some grounds for the assumption that the Moon is inhabited. Beer and Mädler were the first to establish that the Moon could not be inhabited, at least not by the higher forms of life. It is interesting to note, however, that only 120 years ago broad sections of the people were very much inclined to believe that multi-form life existed on the Moon.

An interesting example of this is the mystification of an American journalist who took advantage of the great popularity of astronomer John Herschel and his trips to South Africa to observe the unstudied southern sky. The journalist published in the *New York Sun* a striking account of the discovery of remarkable forms of life on the Moon made by Herschel with the aid of a 20-foot telescope, greatly magnifying and illuminating images in the focal plane. The descriptions of ape-like people with wings, like those of bats, and even stranger creatures of spherical form, who were coasting down the slopes of mountains with great speed, struck the imagination of the credulous readers.

The newspaper, which published these accounts, rapidly increased its circulation several-fold. Such serious publications as the *New York Times* and the *New Yorker* declared that these discoveries of Herschel's had launched a new era in observational astronomy.

All this nonsense was, of course, denied by Herschel as soon as he found out about it, but it is important to note that such inventions fell on very favourable soil.

Petersburg, too, had its sharp journalist who published a book on the inhabitants of the Moon in Russian. He

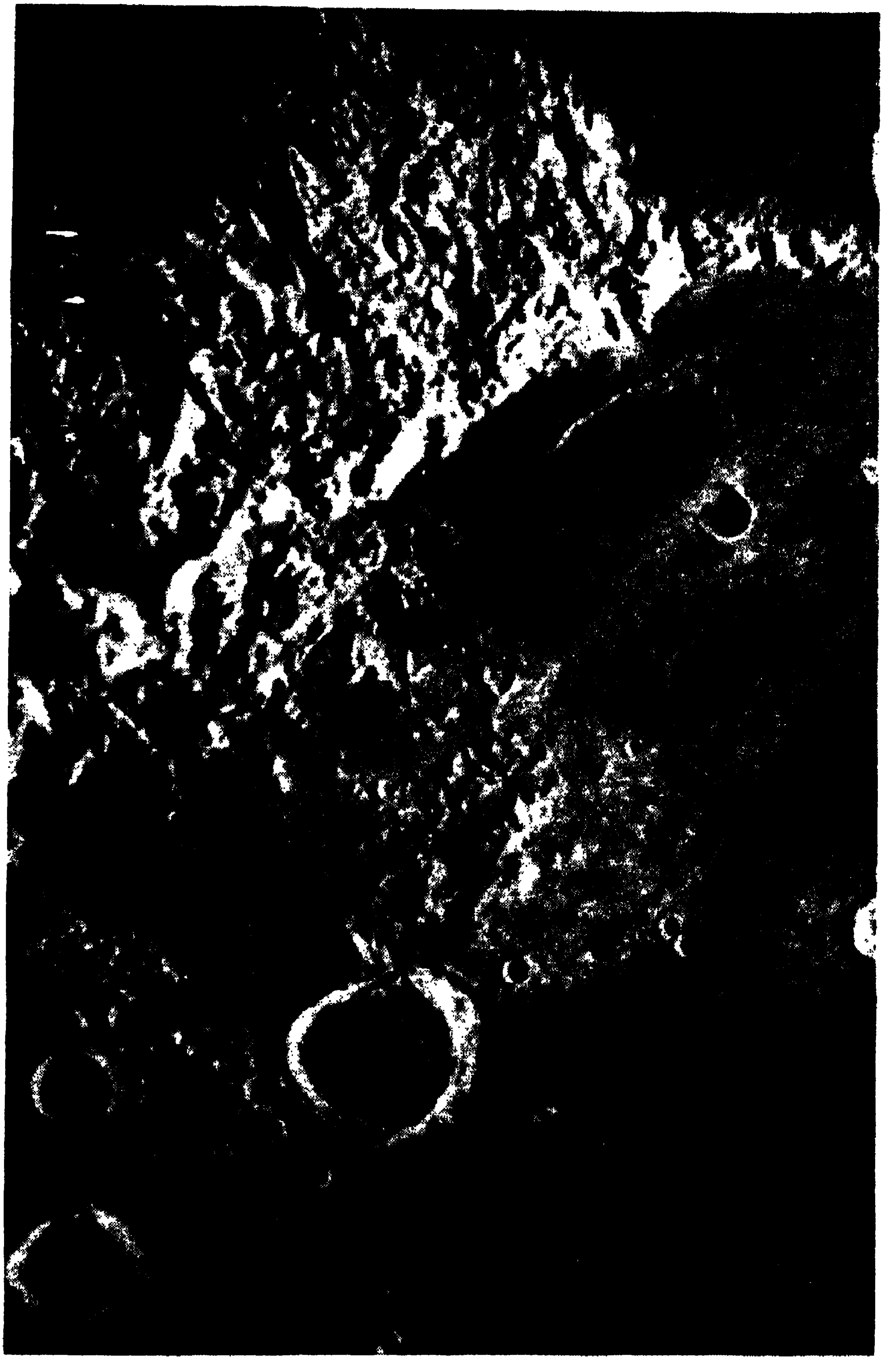

Fig. 31. Apennine Mountains

described Herschel's "discoveries" even more pertly. The appearance of this book was severely criticized by V. Belinsky who thought it was a mockery of science.

Though the existence of thinking beings on the Moon was disproved by the works of Beer and Mädler the existence of animals and plants was until very recently considered probable. William Pickering, the well-known astronomer of the end of the 19th and the beginning of the 20th centuries, found in the lunar crater of Eratosthenes, which closes the Apennines, a number of strange dark spots. The spots showed regular changes and even displacements in every lunation. He offered an explanation (1924) according to which these spots were swarms of insects. He thought the spots in their size resembled the herds of buffalo a lunar astronomer might have seen on the vast prairies of North America about a hundred years ago. The great authority enjoyed by William Pickering commanded attention to his strange hypothesis, but today no one takes it seriously any more.

However, the changes on the Moon still disconcert the observers and force them to look for an explanation of these phenomena in the fact that they are supposedly connected with the development of vegetation. These changes of a more or less regular nature recurring every lunation were observed, for example, in the craters of Endymion, Grimaldi and Riccioli. Thus, for example, spots observed in the Endymion appear more grey than the general tone of the crater's bottom; they expand or narrow down and even disappear depending on the rise of the Sun over the horizon. The same W. Pickering was sure it was all determined by developing and dying vegetation.

In another crater, Aristyllus in Mare Imbrium (Sea of Showers), Pickering discovered two parallel bands, he named canals, whose contrast grows as they are heated by the Sun rising over the horizon. Recently Moore pointed out an interesting phenomenon of a similar nature inside the well-known crater of Aristarchus, the brightest spot on the lunar surface well seen in an ashy light even on the unlighted part of the lunar disk.

As early as 1868 Phillips found that when the Sun rose over the bottom of the crater of Aristarchus and the shadows, cast by the banks, grew sufficiently short, it was possible to see very weak dark radial bands in it. The bands gradually grew darker and became more distinct. In large telescopes one could see these bands divided into a number of separate small spots. During their greatest development, as Moore points out, they first reach the internal banks of the crater spreading out from its centre and then even transcend the banks into the surrounding terrain. Such changes were also observed in the small crater of Birt, situated in the southern part of the lunar disk near the well-known "Straight Wall"; in 1949 Moore discovered similar bands of variable intensity in the crater east of Bullialdus in Mare Nubium, etc. According to Moore, 20-25 analogous craters can be pointed out, but Aristarchus is the largest and most accessible.

In 1951 Moore assumed that these phenomena were connected with a development of vegetation. He imagined that deep radial crevices, from which gases of an unknown nature rose, ran from the central crater. At night they froze, but highly heated by the Sun in the daytime they affected the soil and fostered the development of vegetation. The greatest amount of gases was emitted in the region of the central hill, which was the centre of volcanic activity and that was why the vegetation spread from this hill. According to Moore these gases are not water vapours and, certainly, not oxygen, but possibly carbon dioxide. He holds that this lunar vegetation is absolutely different from that on the Earth.

It goes without saying that all these considerations fail to take into account the specific features of living matter and the conditions it requires for its origin and existence.

The authors of these statements may be somewhat exonerated because of their ignorance in problems of biology.

For a more detailed consideration of the problem of life on the Moon we shall first dwell on its physical properties. Even the naked eye freely discerns numerous dark spots on the lunar disk which have been given the names of seas, but which are really basins of hardened lava of a glass-like nature. These spots were named by Riccioli, Galileo's pupil, who was the first to put them on the map. The Mare Crisium, the isolated oval sea visible on the edge of the lunar disk several days past the new Moon, was, in all probability, given its name because sharp changes in weather were connected with the position of the new Moon. These "seas" mainly concentrated in the northern hemisphere of the Moon form a continuous band everywhere always maintaining an approximately circular form. If the Mare Crisium were located near the centre of the lunar disk we should see it in the form of a rather regular circle. The same can be said about the Mare Imbrium, the enormous plain, bordered in the South by the Apennine Mountains, the highest mountains on the Moon, the Caucasian and Alps Mountains in the West, a number of craters and ring mountains, of which Plato and the steep wall of the Sinus Iridum bay are particularly visible, in the North, and gradually merging into the general surface of the Oceanus Procellarum in the East.

Mare Tranquilitatis, to some extent Mare Serenitatis and other maria also have a similar circular shape if not too deformed by other overlying formations. The circular form of depressions is generally the most widespread type of lunar relief. Among the immense maria nearly a thousand kilometres in diameter, ring mountains—plains surrounded by a ring wall—craters and, finally, hardly visible hollows, pores, one can trace the continuous succession of formations. The large ring-shaped mountain like Grimaldi in no way differs from a small sea in form. Nor is there any difference between a small crater and a pore. Through a medium-sized telescope one can count at least 40,000 such formations on the part of the Moon which faces us. Some

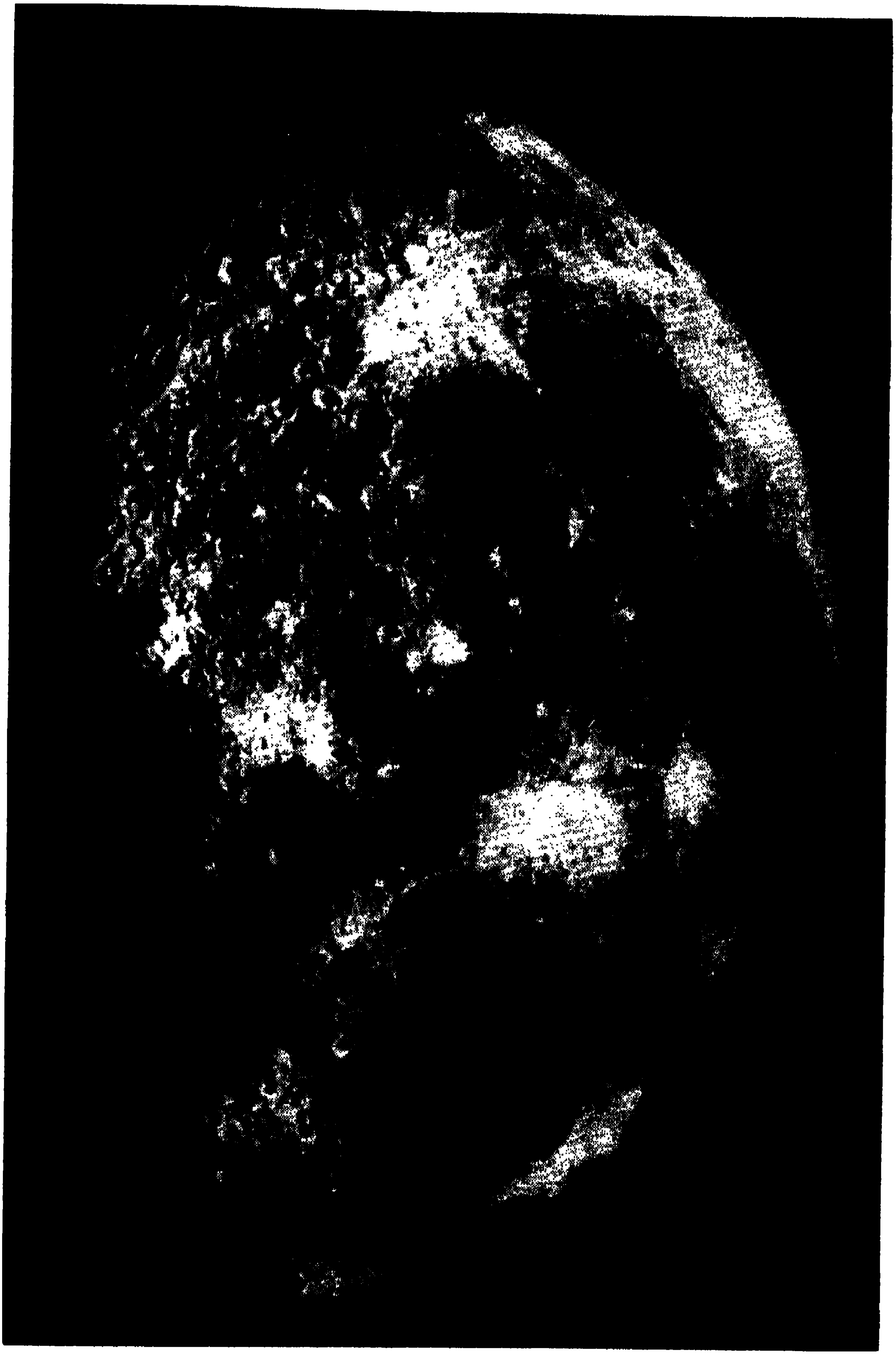

Fig. 32. Moon past first quarter

of them came into being earlier, others later, and often destroyed the existing walls. Mountain ranges surround mainly the edges of the lunar seas and are all without exception of a fault nature, i.e., consist of separate peaks dislocated in a vertical direction in relation to each other. Apparently, the surface of the maria hardened after the formation of the mountainous parts, including the mountain ranges; this is evident from the fact that some of them partly settled and dissolved, as it were, in the surrounding plain. It is in this fault nature of the lunar mountains that they differ radically from the mountains of the Earth which are, as a rule, built of folds, frequently very intricate.

In addition to the ring formations and separate peaks, especially well seen in the maria, under favourable lighting one can observe long cracks—rills—on the Moon which, ordinarily, have nothing to do with the relief of the terrain and sometimes even cross the craters. Such, for example, is the well-known cleft of Hyginus which crosses a crater of the same name and is well seen in the central part of the Moon near the first or last quarter. Near the crater of Triesnecker the entire lunar surface is covered with a dense network of cracks visible even through a small telescope.

Under the illumination created in the central part of the lunar disk it is sometimes easy to see that the cracks, the fault lines are oriented in the same direction over a considerable area (particularly remarkable is the so-called Straight Wall near Purbach). All this shows that these formations are due to internal causes.

Despite the enormous development of geology in the last decades no new explanation of the formations on the lunar surface has been advanced. The so-called Meteorite Theory of the formation of the lunar craters, first proposed by Gruithuisen in 1824, is still seriously debated today. This theory was soon forgotten but was later revived by the English astronomer Proctor, who in his subsequent works rejected it himself. It is, nevertheless, supported by many astronomers even in our time. *The Face of the Moon*, a voluminous book by Baldwin in which various arguments are cited in its favour, is devoted to this theory.

Individual circular craters could, no doubt, have formed as a result of the fall of large meteorite masses as was the case in some regions of the Earth's surface. In these cases, however, no formations with the profile of lunar ring mountains and, especially, central hills, result.

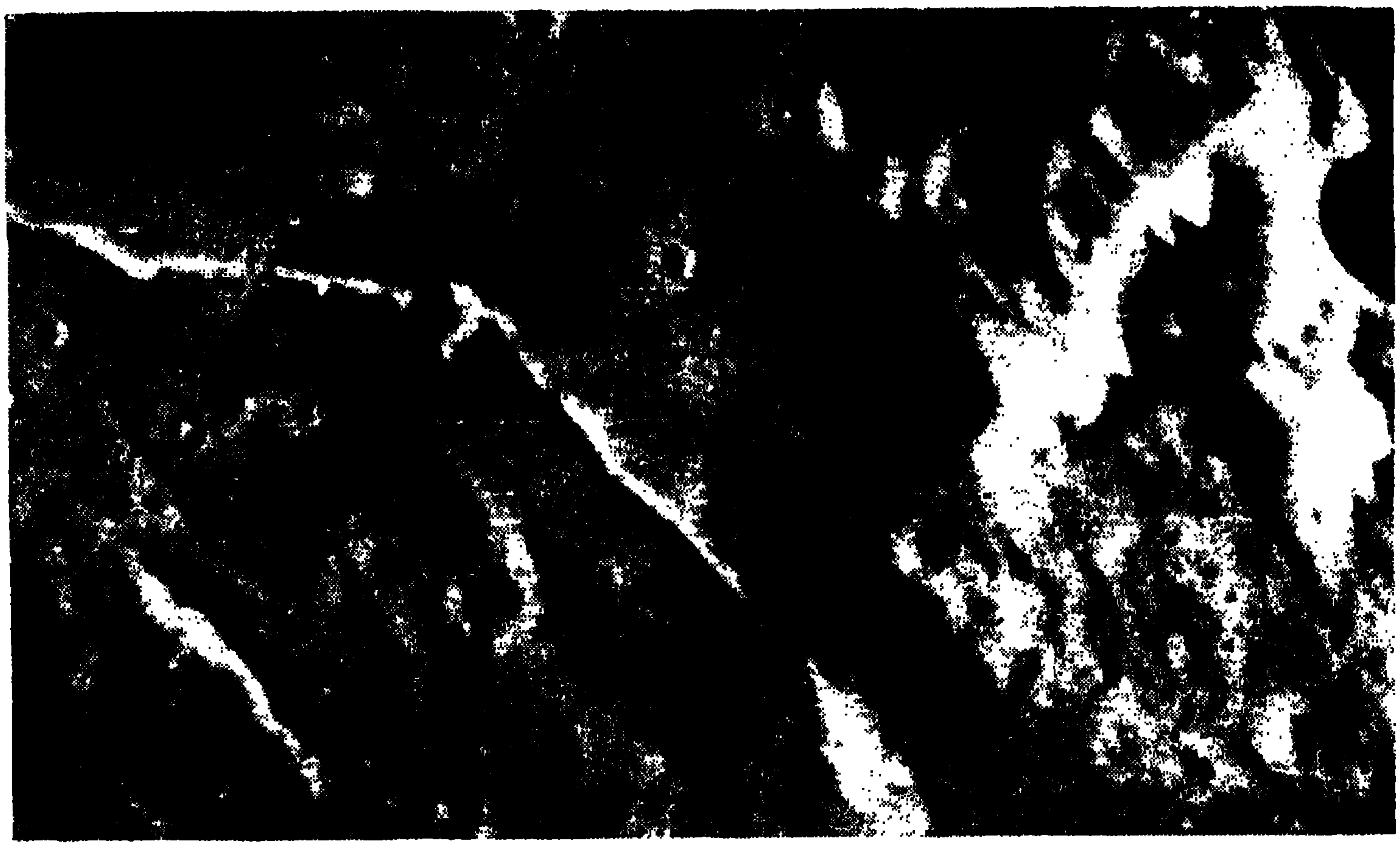

Fig. 33. Rill of Hyginus

The following principal objections may be made against the Meteorite Theory. Firstly, the lunar craters show a certain regularity of distribution. The smaller ones are arranged mainly along the edges of the walls of the large ring mountains. Double craters are frequently encountered. In a number of cases there are close chains of small craters or pores. But the meteorites should have fallen more or less accidentally and should not have left systematic traces of their falls. Secondly, various layers belonging to different epochs can sometimes be observed in the same formation. Such, for example, is the well-known Copernicus crater studied in detail by geologist Spurr. Thirdly, the central hills in the craters have, as a rule, small openings—volcanic craters—on their tops. Baldwin had counted 12 of these openings on the tops of the central hills and calculated that if they had also been formed by a fall of meteorites there should have been about 15 such cases for the entire lunar surface, which seems to correspond to the facts. However, Wilkins and Moore have discovered many new formations of this type with the aid of the greatest telescope in Europe—the 82-cm refractor of the Meudon Observatory and the 62-cm refractor of Cambridge Observatory, so that at least 40 of these craters on the tops of the central hills are known today. If we consider the difficulty of observing them we can be sure that their real number is many times as great and that such craters of central hills constitute the rule rather than the rare exception. This is the more obvious since the openings on the central hills are always encountered precisely on their tops and never on their slopes which should have been the case if they had been formed accidentally as a result of falling meteorites.

At the same time a more detailed study of the lunar formations reveals numerous traces of tectonic and volcanic activity. In certain cases the lunar craters turn out to be of a polygonal form; they were formed along the lines of rupture more or less clearly marked by visible cracks or fault lines. Such are the numerous polygonal forms near the central meridian in the middle part of the lunar disk and in the region adjacent to the North Pole. These polygonal forms were studied in detail by Puiseux. As an example we can cite the Ptolemy Circus, which is a vast slightly undulating plain bordered by ledges of cliffs forming an almost regular hexagon. This entire terrain with the Ptolemy, Alphonse, Arzachel, Albategnius, Herschel, and other ring mountains abounds in rectilinear faults which determine the form and distribution of the craters. We can point out, for example, the long line of fault running along the northern edge of Ptolemy at a tangent to the wall of Albategnius. This line abounds in numerous small craters

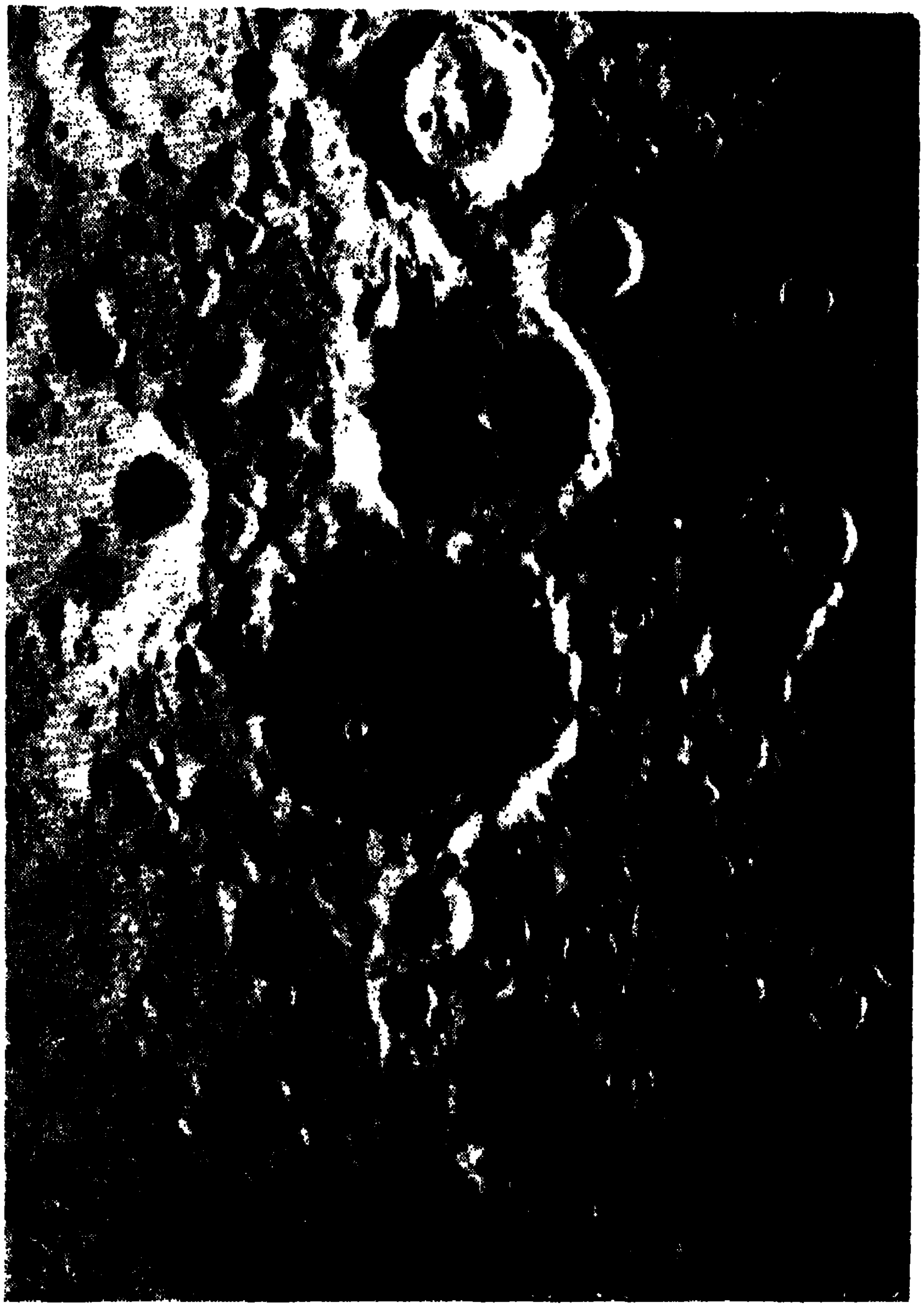

Fig. 34. Lunar calderas Ptolemy, Alphonse and Arzachel

which form a long chain. Such lines coinciding with the contours of the craters or ring mountains determine the abundance of small craters on their walls which can easily be proved by a simple statistical calculation.

Careful observation shows that the structure of the lunar surface is determined everywhere by its tectonics.

For example, on the rill crossing the Hyginus Crater there are approximately 15 small craters. It is remarkable that the direction of the mountain ranges, valleys and other parts of the structure in this region is parallel to the northern part of this rill. Another rill is seen in the western part of this region at a considerable distance from Hyginus; this rill is perfectly rectilinear and precisely parallels the southern half of the cleft of Hyginus. There are many hundreds of such cracks (rills) on the Moon and they are all connected with the relief of the surrounding terrain. Charting these clefts partly open and partly manifest in the lines of the faults shows that they are located mainly in the region of the Mare Imbrium. A more complex combination of the directions of breaks is observed in the region of the South Pole.

Of the other tectonic manifestations we can mention the frequently observed arrangement of craters in long chains and the above-mentioned characteristic "doubling," when we encounter side by side, mainly in the meridional direction, pairs of craters which are very much alike, as, for example, Autolycus and Aristyllus, Aristarchus and Herodotus, Messier and Messier-A, etc. The reason for this is, apparently, in the fact that both craters formed on one and the same tectonic line.

There are numerous traces of former volcanic activity on the Moon. In a number of cases (for example, in the region of Eratosthenes) the outer slopes of the caldera and the entire adjacent area for a distance of dozens of kilometres is littered with erupted fragments. Further away there are deposits of ash in the shape of a system of rays of a more or less regular nature. Lava fields are relatively rare on the Moon. Geologist Spurr, who studied the Moon chiefly from the photographs of Mount-Wilson Observatory, points out only two regions—Fontenelle-A near the North Pole and in the centre of the Moon around a small crater between Manilius and Hyginus—covered by a layer of dark basalt lava. The characteristic canal structure radially fur-

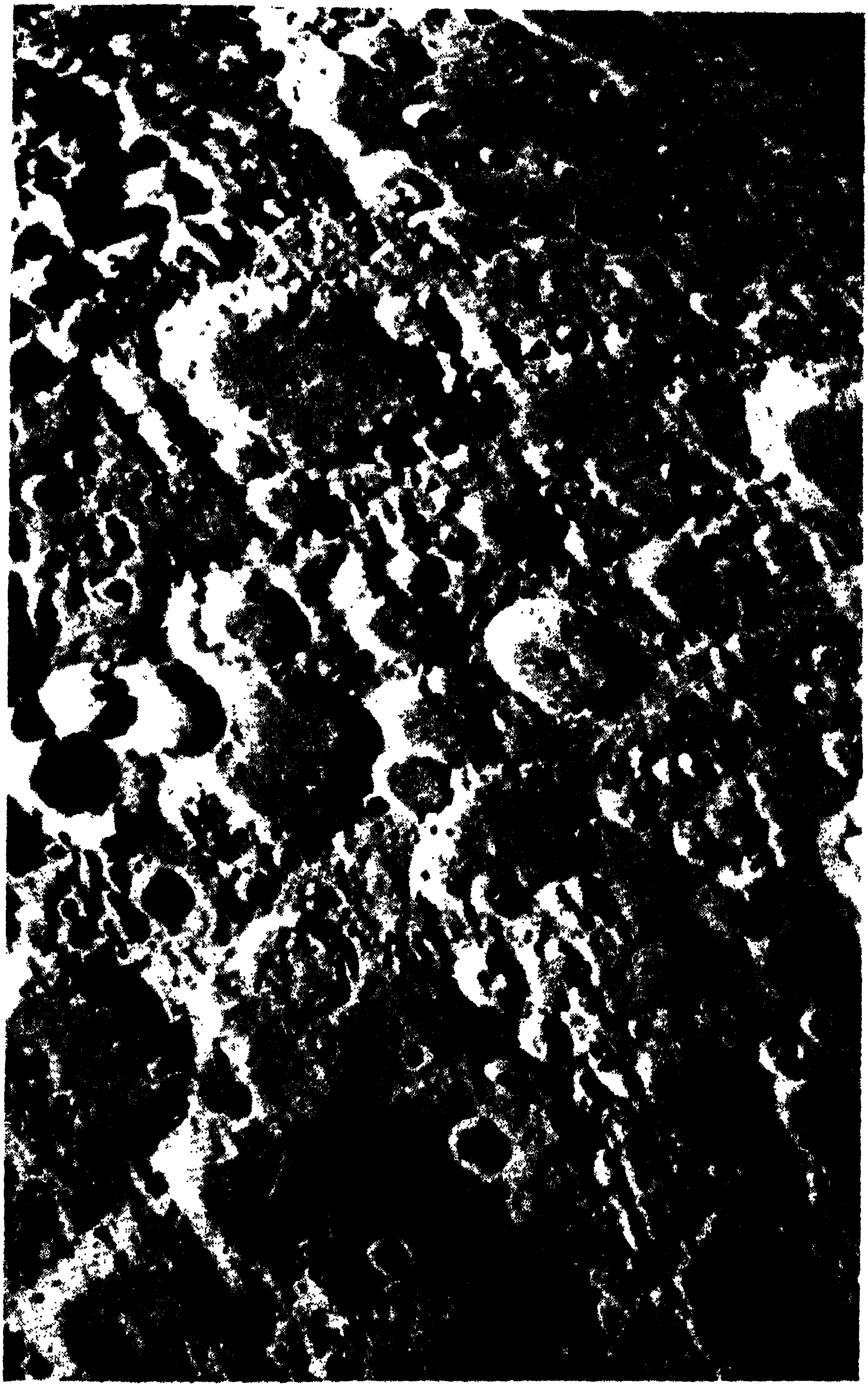

Fig. 35. Mountainous region around Tycho

rowing the outer slopes of the caldera walls is encountered much more frequently. These radial lines are really depressions in the form of ditches. When the Sun is in a low position they are well seen, but they disappear closer to noon. It creates the impression that a liquid had at one time run down the slopes of the craters and eroded such canals—ravines. The only analogue on the Earth that can do a similar thing is water. It is possible that water vapours emitted in abundance during the eruptions of the lunar craters condensed into water which ran down the slopes and without spreading far turned into steam again. This can also explain the origin of the wide and meandering furrows which, apparently, have nothing to do with the cracks and lines of faults. These furrows (for example, in the region of the Aristarchus and Herodotus Craters) arise from the crater and following the relief of the terrain disappear on the surrounding plain.

It is interesting to compare the former volcanic activity on the Moon with the volcanic processes on the Earth. Characterizing the enormous development of vulcanism in the history of the Earth, Academician A. Pavlov gave the following examples: "The Columbia River and its tributary—Snake River—cut over a long distance through hardened basalt lava hundreds of metres thick, and this lava covers a vast space 150-300 kilometres in diameter with no traces of volcanoes which poured out this lava as if the lava simply came out of cracks in the Earth's crust and flooded an entire region burying its original relief.... Still more remarkable is the ancient lava eruption in the region of the upper reaches of the Yellowstone River, the site of the famous Yellowstone National Park occupying an area equal to one-third of former Moscow Gubernia. This somewhat hilly plateau midst the Rocky Mountains with an average height of 2,400 metres is a colossal mass of lava, at one time erupted into this space, hemmed in by the mountains where it formed a lava lake which flooded the bases of the mountains up to a height of 500-600 metres. The lava of this lake poured in some places through the gaps in the mountains into the neighbouring mountainous regions."[1]

Similar basalt streams also occupy an enormous space in other places. For example, in the North-West of the U.S.A. a basalt plateau occupies an area of 15,000 square miles. We find a similar phenomenon in West India. Analogous masses of basalts in the northern part of the British Isles possibly stretch under the ocean to Iceland and take it in.

With such powerful manifestations of volcanic activity on the Earth, continuing to-date despite the constant action of water and winds, it must be acknowledged that the volcanic activity on the Moon was relatively weak. Taking into consideration the ease with which the ash was erupted from the lunar volcanoes because of the small value of gravity (one-sixth of that on the Earth) and the absence of an atmosphere it may be said that these eruptions cover generally an insignificant area.

Wright points out that the trajectory of the bodies erupted from the lunar craters at the same initial velocities and angle of eruption must be 20-50 times as long on the Moon as they are on the Earth. Despite this one of the largest fields covered with ash and connected with the Copernicus Crater stretches only for 600 kilometres in the radial direction and occupies an area of approximately one million square kilometres.

At the same time in the eruption of the Krakatoa in 1883 the clouds of ash erupted to a height of 50 kilometres floated for a period of several months around the entire Earth, while during the eruption of the Tomboro in 1815 the ash was erupted over an area of about two million square kilometres.

Thus, a detailed study of lunar forms enables us to judge about the formation and development of our satellite. It is quite probable that the formation of the lunar maria was a secondary phenomenon and was caused by a partial melting of the thin lunar crust with the erupted magma flooding in some cases the neighbouring sectors.

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[1] A. Pavlov, *Volcanoes, Earthquakes, Seas and Rivers*, Moscow 1948, pp. 30-31.

It strikes very many as strange that the ring forms of relief so usual on the Moon are, as a rule, non-existent on the Earth. This is explained by the uncommonly rapid destruction of the earthly forms by water and wind. As a result of this destruction entire mountain ranges are razed to the ground and disappear, the more so the volcanic ring-structure formations.

Only two regions on the Earth are volcanically active today: the region of the Mediterranean and that of the Pacific volcanic arc. We can mention in connection with this the well-preserved crater field consisting of a number of closely arranged calderas in the vicinity of Naples. Many other calderas have been discovered on Kamchatka by A. Zavaritsky as a result of aerial photography. The walls of these calderas are partly eroded and in some places broken, but well discerned from the air. It stands to reason that such calderas should have long since disappeared in the ancient volcanic regions of the Earth.

Very weak volcanic activity still continues on the Moon. Almost any scientist who has studied the Moon for many years under different lighting can cite several examples of slight changes. Thus, for instance, W. Pickering pointed out the changes in the region of the bottom of the Circus of Plato, in the vicinity of Eratosthenes, Aristarchus and elsewhere. These changes are sometimes manifest in the form of poorer local visibility of different details, as if a light mist were hanging over the lunar relief. Sometimes there are changes in the contours of separate spots depending on their illumination or insolation.

The crater Linné offers, perhaps, a more authentic example of a real manifestation of the internal forces on the Moon which occurred before the eyes of astronomers. This crater is conspicuously situated in the Mare Serenitatis; it has been repeatedly observed, measured and charted by Lohrmann, Mädler and, especially, Schmidt. The drawings made by Schmidt in 1841-1843 show it as a very conspicuous crater with a diameter of nearly six miles. Mädler noted its considerable depth and absence of a central hill.

But observing the Mare Serenitatis again on October 16, 1866, Schmidt failed to find this crater. Instead of the deep depression there was only a whitish spot. The numerous observers who had taken notice of this exceptional object confirmed that the formerly described deep crater was really no more. Soon after Schmidt's report many observers found only a relatively shallow depression with a 6-mile diameter which later, apparently, disappeared, since today, according to Thornton who investigated Linnaeus with a powerful telescope, there is only a whitish spot of variable size and an elevation with a small and deep central crater. It, thus, appears as if a rather substantial and deep crater disappeared from the surface of the Moon between 1843 and 1866. The cause is unknown, but it can, evidently, be explained only by a manifestation of volcanic activity. In all probability the internal magma filled the crater and formed an elevation with a small central depression.[1]

We can mention other similar and no less authentic cases. At the western edge of the Mare Crisium Schröter in his time pointed out and described a rather large crater with a 23-mile diameter, sharp walls and dark bottom visible under any illumination conditions. He chose this crater as a base, which testifies to its good visibility. By the middle of the 19th century this crater almost fully disappeared leaving only a barely noticeable depression between two mountain peaks. Mädler transferred the name of this crater—Alhazen—to another object situated somewhat to the South, so that present-day Alhazen has nothing to do with the crater of Schröter. Here, too, we are, apparently, dealing with a real change in the relief of the Moon.

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[1] Crater Linné is not marked on Cassini's map either (end of 17th century). The crater was, evidently, never very easy to observe.

Considerable interest was also caused by the double crater Messier (one of the components is now called Pickering) situated in the Mare Foecunditatis. This double crater is interesting in that a short line resembling the tail of a comet runs eastwards from it. The craters are divided by a small mountain range. Nininger recently expressed a strange idea that these craters are the two openings of an immense tunnel driven in this mountain range by some meteorite. Suspicions concerning the possible change in the crater Messier are based only on the insufficiently reliable testimony of Beer and Mädler to the effect that both craters were exactly equal, though it is well known that they are noticeably different today. This discrepancy is, probably, due to the differences in illumination during the same lunation. Besides, according to Klein, this region is sometimes covered by a mist which in these cases partly conceals the separate details of the crater. On August 20, 1950, Moore found a shiny white spot which, it would seem, could not have been unobserved before. Generally speaking, this region of the lunar disk deserves attention.

Thus, we can assume that phenomena of a volcanic nature occur in some cases on the Moon even today and that these phenomena cause changes not only in the colouring of details of the surface but also in its relief. But, of course, reports of such phenomena must be treated very cautiously.

It is essential to note that the lunar surface can be greatly heated by solar rays and that it can quickly give up its heat into space during its cooling.

Working with sensitive thermocouples and making the necessary corrections to separate the higher frequency solar radiation reflected directly from the lunar surface Pettit and Nickolson have shown that the temperature at the lunar equator rises to 100°C and higher when the Sun is in its zenith and drops to 14°C at sunset, while during the long lunar night it goes down to —150°C, i.e., nearly to the temperature of liquid air.

This denotes a very low heat conductivity of the lunar surface, approximately 1,000 times as low as the usual conductivity of the earthly rocks, for example, granite, sandstone, etc. During lunar eclipses, when the shadow of the Earth approaches and occults the lunar cliffs their temperature drops nearly 140°C within one hour.

Interesting results were obtained by Piddington and Minnet in Australia in 1949. With the aid of a metal reflector 120 cm in diameter they focused the radio-rays emanating from the weakly heated Moon on a radio-receiver and measured their intensity. The temperatures obtained proved much more uniform than those formerly found by Pettit and Nickolson on the basis of light-rays. The highest temperature was recorded not at noon, but approximately three earthly days after noon. It may be supposed that the outer layer of the lunar surface, which is not very heavy, is sufficiently transparent to radio-rays since the authors measured the temperature of some layer located at a certain depth where the highest temperature sets in noticeably later than the moment of the highest position of the Sun.

Thus, the lunar surface is covered with a thin layer, probably, of volcanic ash and partly of meteor dust. It is, probably, not thicker than a few centimetres. The harder lunar rocks, whose temperature fluctuates much less, are located under this layer. The existence of so dispersed a layer also testifies to the former lunar vulcanism.

We shall now dwell on the question of whether there is at least a rarefied atmosphere on the Moon since without it there can, certainly, be no life.

It may be theoretically expected that relatively heavy gases, such as molecular oxygen and nitrogen, may persist throughout the history of the development of the Moon at a sufficiently low temperature of its surface. In this case, however, we must take into consideration precisely the highest temperature of the Moon which may considerably exceed 100°C. In solving the problem of whether there was an atmosphere on the Moon the data of the observations, which established the obvious absence of twilight on the

Moon, the lengthening of the horns of the lunar crescent, etc., were taken into account. But this did not lead to any decisive conclusions. Observation of the periods during which stars are occulted by the Moon revealing the possible refracting ability of the lunar atmosphere also failed to yield any constructive results, primarily, because of the considerable irregularities in the contours of the lunar edge. The findings of the density of the lunar atmosphere according to the time elapsing between the disappearance and appearance of a star turned out absolutely contradictory.

A much more efficient method was proposed in 1942 by the Institute of Astronomy and Physics of the Academy of Sciences of the Kazakh S.S.R. This method grows out of the fact that the rarefied lunar atmosphere observed near the terminator on the unlighted part of the lunar disk at the first or last quarter must disperse the solar light and fully polarize it. At the same time the background against which this lunar twilight is projected must be absolutely unpolarized, i.e., emanate light oscillations oriented in any planes passing through the direction of the ray. In point of fact this light background placed on the dark surface of the Moon is composed of the light of the Moon itself dispersed in the terrestrial atmosphere and to some extent the so-called earth-shine which represents the illumination of the Moon by the Earth. But if dispersed light is observed at a small angle from the source it always appears unpolarized whatever the nature of the dispersion.

Thus, to solve the problem of the lunar atmosphere it is enough to find out whether there is any admixture of polarized light in the illumination of the background on the Moon at the first or last quarter near the terminator, i. e., near the centre of the lunar disk. This admixture can be produced only by lunar twilight. If this be the case the total amount of dispersing particles, i.e., the mass of the lunar atmosphere, can be judged by the amount of polarization. This method is extraordinarily sensitive because the lunar atmosphere illuminated by the Sun at a right angle to the observer is compared only with the dark background of the earthly atmosphere which, at night, is illuminated several million times as weakly.

The photometric measurements taken at the mountain observatory of the Institute have shown that there was no noticeable polarization on the Moon beyond the terminator. Hence it was possible to calculate that the mass of the lunar atmosphere in the column over a unit of surface must be at least 2-3 million times as small as the similar mass of the column of the earthly atmosphere. The more systematic observations conducted by Y. Lipsky by the same method but under worse atmospheric conditions led him to the conclusion that the Moon has an atmosphere with a density approximately 10,000 times as low as that on the Earth. Similar measurements were recently taken by the polarization method by Lyot at the Alpine observatory, Pic du Midi, some 3,000 metres above sea level, but they failed to establish any atmosphere on the Moon. To be exact, the maximum density of the lunar atmosphere must be at least one-millionth that of the Earth.

It is interesting to note, however, that there are local dimnesses of the type of temporary mists on the Moon which were registered by many observers. In 1892, when Jupiter was occulted by the Moon, W. Pickering observed a dark band crossing the disk of the planet; the band crossed the system of its bands and ran parallel to the lunar edge. If this observation was correct the aforesaid phenomenon was of a temporary nature because it was not confirmed later by other observers under similar conditions. An interesting example of such dimnesses was observed by Thornton in the Valley of Herodotus on February 10, 1949. Through his 45-cm telescope under good atmospheric conditions he saw a puff of whitish steam which hid the details over an area of several miles while the surrounding terrain remained perfectly clear and was well seen. Moore tells that in 1949 he saw the whole crater Schickard filled with a whitish mist which concealed the details on the bottom of this crater. As far as we can see the observers usually judge about the existence of such fogs by the fact that separate details on the bottom of the crater or in its vicinity are invisible while other details can be seen quite clearly. On the basis of this we can speak of local dimnesses on the bottom of a number of craters, for instance, Plato, Timocharis, etc. Moore describes quite a few of these cases.

From all of the foregoing we can, apparently, make the following most plausible conclusion. A very small amount of different gases still escapes into the atmosphere of the Moon from many cracks and still weakly active volcanoes. There was active volcanic activity on the Moon in the past, and this is testified to, for example, by the vast regions of the lunar maria which are large basins of hardened magma and an enormous number of craters and ring mountains which are also formations of a tectonic nature. In the distant past there were immense areas on our satellite with a high temperature—in the neighbourhood of several hundred degrees—owing to which the abundant gases discharged from the interior of the Moon during its formation dissipated into cosmic space. Even carbon dioxide, let alone oxygen or nitrogen, could not persist on the Moon where the velocity of escape is but 2.4 km/sec.

Only weak traces of the original atmosphere replenished by a negligible quantity of gases, apparently still liberating from the Moon, can remain on the Moon today. There can, certainly, be no water on the Moon in either liquid or solid states and it does not form part of the lunar gaseous mantle in any measurable quantity. Under these conditions life on the Moon is, certainly, out of question.

Chapter VI

THE MAJOR PLANETS

Jupiter, Saturn, Uranus and Neptune, the giant planets of the solar system, sharply differ from the planets of the terrestrial type by their large masses (from now on we shall call them the major planets), relatively low density, rapid rotation about their axes and the abundance of light gases—hydrogen and helium. In relation to water their mean densities are 1.34, 0.71, 1.27 and 1.58 respectively. Saturn is noted for its particularly low density. Taking into consideration its low temperature and great mass (80 times that of the Earth) we can conclude even without accurate calculations that this planet must be in a gaseous state and if it has a solid core, which must, naturally, be under great pressure of the higher layers, it must be negligibly small in comparison with the radius of the planet. It is well known that even under normal pressure solid oxygen has a density of 1.45, nitrogen—1.02 and ammonia—0.82; but all this considerably exceeds the mean density of Saturn. Only the tremendous quantities of hydrogen and helium in a gaseous state can explain the low density of the planet as a whole.

An analogous conclusion can also be made about Jupiter whose mass is 318 times that of the Earth. A detailed investigation of its internal structure has shown that the heterogeneity of the structure at the high rate of rotation can be explained only by enormous amounts of hydrogen and partly helium throughout its mass. The heavier elements can constitute in this planet, as in the Universe generally, only an insignificant admixture. The mass of Jupiter contains an amount of different elements very closely corresponding to their natural quantity in the Universe. This conclusion is also fully confirmed by recently conducted direct observation of the spectra of the major planets.

We shall now consider in greater detail what can be directly observed on the major planets, what their physical peculiarities are and to what extent these planets can be fit for the development of organic life.

Gigantic Jupiter, which is relatively near to us and which is the largest and is, therefore, easily observable even through small telescopes, is a typical representative of the major planets. Suffice it to say that magnified only 40 times Jupiter appears to us like the Moon seen by the naked eye.

Jupiter has larger angular dimensions than, for example, Venus at the moment of its greatest brilliance though it is inferior to the latter in brightness. The reason for this is that Jupiter sheds a rather dim yellow light, whereas Venus appears dazzlingly white. This is due to the great distance from Jupiter to the Sun in which the solar rays are 50 times as rare as they are in the distance from Venus to the Sun.

It might be assumed that Jupiter's temperature is very low because it receives so small an amount of heat from the Sun. Attributing to it the properties of an absolutely black body we can very easily calculate that at a temperature of —150°C this planet must radiate as much heat into space as it receives from the Sun. It is the more surprising that on Jupiter, which should be a perfectly hardened body, everything is in stormy motion. Wide dark belts of a brown shade and rather complex structure stretch on both sides of the light equatorial zone. Numerous less intensive and, to a considerable extent, variable belts are located in the moderate regions of the planet, but the polar spaces are enveloped in a uniform greyish shade and show no details. Sepa-

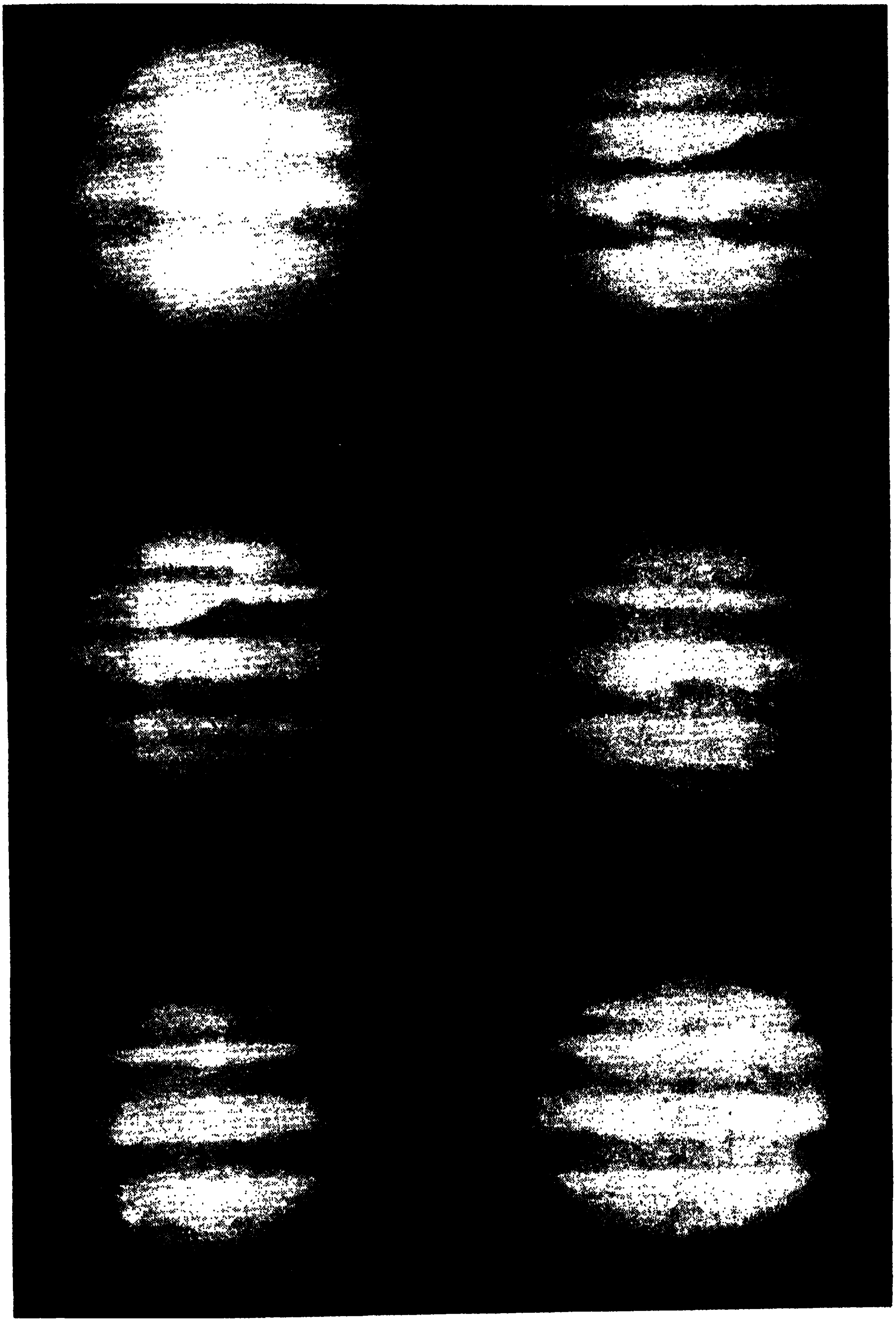

Fig. 36. Photographs of Jupiter

rate light clouds constantly form in different regions of the planet, but mainly near the equator dark bands sometimes divide into small chains of some dark formations and constantly change their structure which seems extraordinarily complex. But the most remarkable formation on Jupiter is, undoubtedly, the red spot which became particularly visible in the 70's of the 19th century. At that time it looked like an isolated red oval-shaped cloud hanging in space between the south-equatorial and south-moderate belts. Part of the first band turned out to be destroyed and the red spot, surrounded on all sides by a layer of white clouds, was located in the hollow which had thus formed. Subsequent studies of the spot revealed even more interesting peculiarities.

Already Cassini established that the period of Jupiter's rotation constituted only 9 hrs 50 mins. Each point of the planet's equator moves at the rate of 10 km/sec. If the planet rotated only 3 times as fast it could no longer exist as an independent body because the force of gravity on its equator would equal the centrifugal force developed by the rotation. Thus, the reserve of stability is not very big for Jupiter; it is much less than for the Earth and, especially, for the Sun. Academician A. Belopolsky has accumulated observations of the positions of the numerous spots in the different belts of the planet and has incontestably established the formerly suspected fact that Jupiter rotated with different velocities at various latitudes. Essentially two principal periods of rotation can be distinguished. One of them corresponds to the equatorial zone proper and constitutes approximately 9 hrs 50 mins, the other pertains to all the other regions of the planet and equals 9 hrs 55 mins.

The dark equatorial belts are precisely on the borders between both zones and it is just in these belts that the rapid change in rotation occurs. Each dark band of a secondary nature similarly limits the zonal streams moving at different rates on Jupiter, though the difference in these periods of rotation is expressed only in a few seconds. Detailed studies of this phenomenon based on many years of observation were made by the English amateur astronomer S. Williams.

Thus, Jupiter has an equatorial acceleration, i.e., a greater rate of rotation at the equator than in the other parts of the planet. This phenomenon was hitherto discovered in the solar system only in the Sun with the difference, however, that the rate of the Sun's rotation changes constantly from the equator to the poles and within very wide limits, namely, from 25 to 30 days.

Jupiter's red spot presents curious peculiarities also as regards rotation. Its motion on the surface of the planet is inconstant. In 1899 it was the slowest and lagged behind the other formations which outstripped it in their rotation about the axis. At the same time it is the only constant formation on Jupiter. Galileo did not know the red spot because his very imperfect telescopes did not make it possible for him to discern even Saturn's ring. The red spot was first discovered by Cassini in 1664. Since that time it has appeared and disappeared several times without noticeably changing its shape or the latitude of its location with the reference to Jupiter's equator. It has been observed during the last centuries by Maraldi, Schröter, Gruithuisen, Dawes, Lohse, I. Kortazzi, F. Bredikhin and many others. Having again become visible in 1870, the red spot appeared in an unusually contrasting form and especially bright. Since 1882 its intensity gradually began weakening and today the spot has an extremely weak colouring barely discernible even through large instruments. The same hollow in which this spot lies and which moves together with it still persists in the south-equatorial belt. Numerous observations show that the red spot exerts a certain influence on the clouds and belts which surround it. The space between the south-equatorial and the south-moderate belts in which the spot is located rotates somewhat faster. The clouds which form in this space must, therefore, necessarily come in contact with the spot. It might be expected that, if the red spot is located at a relatively low level as it appears judging by its slow rotation and very constant form, the clouds floating at a considerable altitude in the planet's atmosphere will pass over the spot. But this never occurs. When approaching the spot the clouds usually divide into two streams. One stream heads North, the other—South. The clouds move around the spot in the space between the spot and the corresponding dark belts and having passed it reunite into a single stream. It occurs as if the red spot were the centre of repelling forces which are the greater the more intensive the colouring of the spot.

As the spot grows less contrasting its repelling forces considerably diminish and the spot begins to be enveloped, first in the centre and then at the edges, by a uniform whitish layer which finally hides it from the observer. The place that indicates the position of the spot is the hollow in the dark equatorial belt which takes part in all its motions.

Speaking of Jupiter we cannot help mentioning another remarkable, though, perhaps, not so constant, phenomenon. It is the veil or, in the terminology of the French observers, the "big southern perturbations." It consists in the fact that the space between the south equatorial and moderate belts appears veiled by a more or less uniform grey cover through approximately latitude 90°. Moving much faster than the red spot the veil comes in contact with it approximately every other year. But even now, when the red spot is invisible, we can be sure that the veil never covers it. When the veil "catches up" with the spot it is observed that both belts located on either side of the red spot sharply expand and grow more distinct. It may be assumed that the black matter of the veil moves around the spot under the influence of the repelling forces. Sometime later the western edge of the veil shows itself on the other side of the red spot and it stands out sharply against the grey background of the veil. On the whole both these formations, no doubt, exert a perturbing influence on each other. Away from the red spot the veil has a more or less uniform structure. But when it passes through the spot it acquires chaotic contours while the surrounding belts grow much darker and separate small black spots, sometimes isolated and sometimes collected in chains and mixed with the light parts of the veil, form on them. In addition a considerable change in the angular velocities of the spot and the veil are observed each time.

We could also mention the observations of many scientists who have noticed and described other cases of considerable perturbations on Jupiter and the appearance of unusual formations with fast displacements, sudden break-up of vast clouds into separate spots, etc.

But where does the energy required for these fast and considerable changes come from? The principal source of atmospheric energy on the globe is the heat received from the Sun. But Jupiter gets very little solar heat. From this it might be possible to conclude that the source of energy on Jupiter is its own internal energy, i. e., that Jupiter has not fully cooled as yet and that it has a rather high temperature at which a partial formation of water clouds is possible only in its outer layers. The great mass of Jupiter would seem to confirm the correctness of this conclusion. But it had to be given up after Coblenz (first in 1914 and then in 1922) directly determined the temperature of Jupiter's cloudy surface. It was ascertained at the same time that the radiation sent to us by Jupiter was a reflected radiation from the Sun. This planet has hardly any heat depending on its own temperature. Jupiter's temperature, according to Coblenz' findings, turned out close to —140°C. Subsequent findings have confirmed this conclusion.

As a matter of fact there should have been nothing surprising in this result. Had Jupiter's atmosphere contained appreciable quantities of water vapours it would have been infallibly discovered by the spectroscopic method. It is precisely the spectroscope that decides in this case. Meanwhile Jupiter's spectrum, which has been studied in detail since the 70's of the 19th century, revealed a considerable number of bands and lines of absorption of an unknown origin, but not one of them belonged to water vapour.

Thus, the solution of the problem of the physical state of Jupiter's visible surface came down to establishing the nature of the bands of absorption in its spectrum. The same bands were discovered in the spectra of the other major planets—Saturn, Uranus and Neptune—their width and intensity being the greater the farther the planet was from the Sun.

Only in 1932 did the American scientists Adams and Dunham ascertain on the basis of laboratory experiments that these bands belonged to compounds of hydrogen with carbon and nitrogen (methane and ammonia) at a low temperature. As the temperature drops the compounds of hydrogen and nitrogen gradually fall out in a liquid state and the absorption lines grow weaker. By the intensity of the absorption lines of ammonia in Jupiter's atmosphere Dunham concluded that the quantity of uncondensed ammonia corresponds to an equivalent layer eight metres thick at a temperature of 0°C and a pressure of 760 mm.

On Saturn and, especially, on Uranus the cloudy layer formed by condensed ammonia is thinner than it is on Jupiter; on Neptune it is practically non-existent because at the very low temperature of this planet all the ammonia should have fallen in a solid state into its deeper layers. The atmosphere consisting of a compound of hydrogen and carbon CH_4 (so-called methane or marsh gas) is, therefore, much more accessible to observation since this compound yields intensive bands in the spectrum. It is, thus, clear that the intensity of methane bands must gradually increase for the major planets the farther they are removed from the Sun, as observations have, in fact, established.

On the basis of experimental comparisons between the spectrum of methane and the spectra of the major planets Adel and Slipher showed in 1935 that a column of this gas 13 metres high at a pressure of 40 atmospheres forms absorption bands intermediate in intensity between the

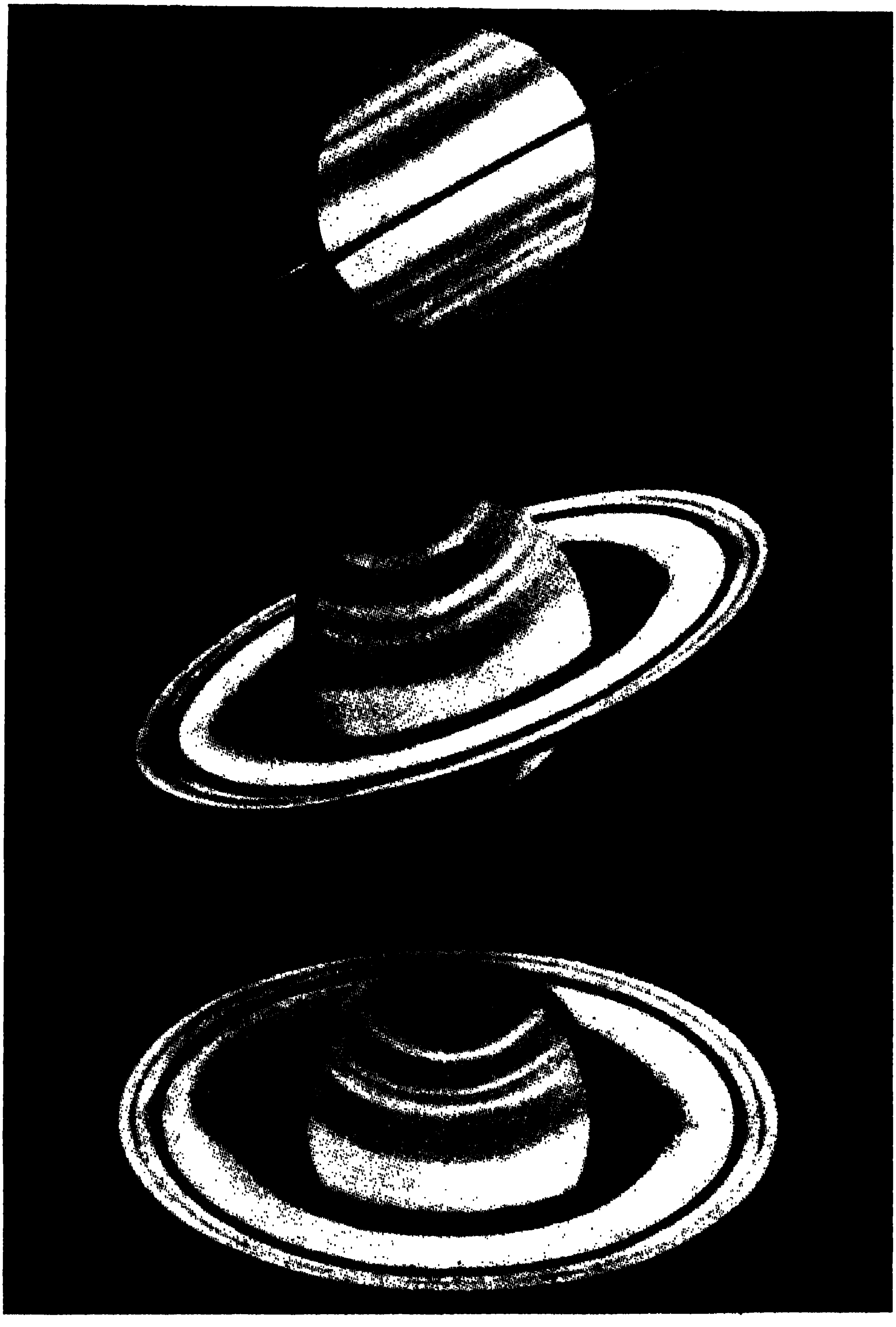

Fig. 37. Saturn from different positions of the observer in relation to the plane of the ring

spectra of Jupiter and Saturn. It also turned out that the methane bands in Neptune's spectrum can be produced by a 40-kilometre layer of atmosphere consisting of methane under normal atmospheric pressure. We shall point out for the sake of comparison that the equivalent height of the terrestrial atmosphere constitutes only eight kilometres. There can be no doubt, however, that the thickness of methane on Neptune is really much greater, but lying deeper its layers can no longer produce any noticeable absorbing action on the solar rays penetrating from without and for this reason do not yield the corresponding spectroscopic effect.

It might be supposed that in addition to ammonia and methane the atmospheres of the major planets also contain other hydrocarbons, such as ethane, ethylene and acetylene. Searches for the absorption lines and bands belonging to these compounds have been fruitless. It appears that all the peculiarities of the spectra of the large planets are fully explained only by the presence of ammonia and methane. Besides, the farther the planet and the lower its temperature the less intensive the ammonia bands while the intensity of the methane bands sharply increases.

We must necessarily acknowledge that the physical properties of Jupiter, Saturn, Uranus and Neptune are the inevitable consequence of their great mass and, hence, the exceptional abundance of hydrogen.

Let us note, in the first place, that various molecular compounds, mainly oxides with different metals, make their appearance already in the atmospheres of the relatively cold stars of the *M* and *N* spectral classes. Where there is an abundance of carbon very intensive oxides of carbon are manifest, which is characteristic of the class *N* red stars. With a still greater drop in temperature carbon dioxide inevitably appears; it forms already at the stellar stage and is a primary gas for the planets.

Condensation of elements with a high melting point, mainly, metals—potassium, sodium, magnesium, aluminium

—begins in the atmosphere of such a body first; oxidized they form minerals which in their composition resemble the primary igneous rocks on the Earth. At high temperatures the oxygen forming part of iron compounds is reduced by hydrogen. This is why iron remains unoxidized and owing to its great density accumulates mainly in the deeper layers. With a drop in temperature approximately to 700-800°C oxygen as an extraordinarily active gas combines with hydrogen forming water vapours. Inasmuch as there is always an excess of hydrogen compared with all other gases all of the oxygen may turn out to be in combination. In subsequent drops in temperature the hydrogen, if it has been retained by the planet, forms other compounds with carbon and nitrogen and in the end yields methane CH_4 and ammonia NH_3.

Since the volume of gas is reduced during the formation of methane this reaction, everything else being equal, is aided by greater pressure, i.e., the greater mass of the planet. With a drop in temperature the amount of methane increases. At 600°C there are nearly equal quantities of carbon dioxide and methane, while at 300°C most of the carbon combines with hydrogen. Generally speaking, the formation of various hydrocarbon compounds is possible, but under high pressure hydrocarbons infallibly change to the same methane. This is why there is always a tendency to form precisely methane at low temperatures; this explains why methane occupies an exceptional place in the atmospheres of the major planets. In addition there is also a reaction between nitrogen and hydrogen with the formation of ammonia which releases less energy and, therefore, occurs less intensively. With an excess of hydrogen, under normal atmospheric pressure and at a temperature of 200-300°C the amount of free nitrogen and ammonia is the same. At a lower temperature the relative amount of ammonia continually increases. With the subsequent cooling water gradually condenses and falls out of the atmosphere. By this time most of the nitrogen has already changed to ammonia, but this can take place only in the presence of suitable catalysts as, for example, iron. Practically, since the solid rocks, which contain oxides of metals, are covered with a layer of ice, electric discharges can act as catalysts aiding in the aforesaid reactions; the existence of electric discharges is quite probable since the strong movements, described above, are observed in the atmospheres of the major planets. At Jupiter's temperature ammonia condenses into white clouds forming the observable surface of the planet.

Thus, the physical properties of the distant major planets of the solar system are explained, particularly, the sharp differences of their atmospheres from the atmosphere of the Earth. The same considerations may be used for any planet with a sufficiently large mass wherever it may form. Such a planet must have an extensive atmosphere consisting mainly of hydrogen and its compounds, chiefly methane, but without compounds of oxygen, especially without oxygen in a free state. At the low temperatures of such planets the compounds of hydrogen and oxygen in the form of ice must be concentrated in the deeper strata of the planet and cannot be accessible to observation, let alone the different mineral compounds which form at high temperatures and can be present only in the much deeper layers. It is doubtful, however, that a massive planet may have a central core composed of a heavier refractory substance. At any rate, the pressure in Jupiter's entrails grows so fast because of the great force of gravity and its outer hydrogen shell is so large that the existence of a solid core in this planet is doubtful.

It should be noted that above Jupiter's observable surface (which is only cloud banks of condensed ammonia) there is only a relatively rare atmospheric layer of gas. This conclusion corresponds with the data of observation.

It has also been possible to ascertain that the scattering ability of Jupiter's atmosphere over its cloudy layer constitutes only one-tenth of the scattering effected by the atmosphere of the Earth. But the density of this atmospheric layer of the planet's visible surface proved very insignificant, and with this density the scattering ability appears relatively large. Hence, the assumption expressed by E. Schenberg that fine dust floats in Jupiter's atmosphere and makes for the increased scattering ability. The presence of dust is, in turn, an indirect indication that in addition to the compounds of methane and ammonia there are also other compounds on Jupiter's surface which in no way affect the state of the absorption lines in its spectrum. This is also testified to by the great diversity in the colouring of the various formations on Jupiter, from white and yellowish to red and brownish. Wild suggests the possibility of the existence on Jupiter and Saturn of a solution of metallic sodium in ammonia which is noted for its bright colouring. It is well known that with a drop in temperature the colouring of this solution fades and it hardens in the form of grey crystals. This corresponds with the higher scattering ability of the atmospheres of these planets and the fact that having a lower temperature than Jupiter, Saturn also has a generally more greyish colouring. The atoms of sodium shine intensely in the atmosphere of the Earth at rather high altitudes and produce bright emission lines in the spectrum of the nocturnal sky. Though this element is present in inter-stellar space it can hardly be doubted that it gets into the upper layers of the atmosphere as a result of turbulent mixing from the lower layers where it is formed by fine droplets of water being blown off the crests of waves in the vast spaces of the oceans. It is precisely in this manner that the numerous aerosols of the terrestrial atmosphere, which rise to its highest layers, may form. There can be no doubt that various compounds and elements enter the atmosphere of Jupiter from its lower layers and this is favoured by the observed enormous turbulence which mixes its outer layers and which is especially intensive in the region of the dark belts parallel to the equator.

To ascertain the nature of the dark belts it is very essential to trace their formation. The north-equatorial belt, which sometimes completely disappears and sometimes appears very wide and intensive, best serves this purpose. Various observers repeatedly studied the peculiarities in the structure of this belt. Laue, Ganski, Bernard and others noticed in it numerous dark grains with very insignificant angular dimensions. In describing the formation of this belt in 1906 Laue noted that an irregular and broken chain of black spots appeared in the place of this belt first. They began to emit a reddish mass which filled the entire zone to latitude 22°. At the same time the black spots changed into large eroded knots which rapidly spread in an easterly direction and formed an uneven knotty band. When the process was over the entire area from the band to the poles was veiled by a reddish-brown or reddish-grey mass. In the end there was a wide and dark belt which gradually changed into a weak veil in the direction of the pole.

It necessarily follows, firstly, that the dark belts and the dark spots on Jupiter are in no way simple intervals between the light formations. It is perfectly clear that there are two types of formations on Jupiter—light clouds, apparently, products of condensation of ammonia, which form the visible surface of the planet, and the dark belts, which are of an entirely different nature. Secondly, the picture of the formation of Jupiter's belts evidently indicates that they are a result of the turbulence which forces the deeper condensations to rise to the surface level. If we consider, according to Helmholtz, that the total circulation of a planet's atmosphere is conditioned not so much by its temperature regime at different latitudes as by its rotation about the axis, we may compare Jupiter's equatorial zone to the trade-wind zone on the Earth though on Jupiter this zone of atmospheric currents is somewhat narrower.

The turbulent movements are, naturally, particularly intensive on the border which divides the currents moving at different velocities. It is precisely in these places that the products of condensation mix, owing to which the outer products disappear and other materials, apparently more heated and having a different colouring, appear from the hypogene layers. Thus, belts appear which must be oriented parallel to the equator and which may at the same time consist of numerous separate relatively rapidly changing elements and turbulence-knots.

Thus, even the external appearance of Jupiter and the other major planets shows that the composition of their surface layers includes not only compounds of ammonia which form the cloud banks but also compounds of various other elements of which it is hard to say anything definite at the present time. Nonetheless, owing to their tremendous mass and excess of free hydrogen the major planets present a striking contrast with the terrestrial-type planets. Even if the large planets did not have extremely low temperatures in their surface layers, the complete absence of water vapours or water in a liquid state in the atmosphere would, in this case, make any life, whatever our idea of it, impossible. Life is all the more impossible in the hypogene layers of the major planets. If the temperature in these layers is not very high the tremendous pressure soon breaks the molecular structure and renders the existence of even neutral atoms impossible. It has already been pointed out that the overwhelming part of Jupiter's mass consists of atomic hydrogen and partly of other elements which in the hypogene layers lose even their electronic shells. Under these conditions the existence of complex and unstable albuminous compounds within the major planets is absolutely impossible.

Chapter VII

OUR CLOSEST NEIGHBOURS—MARS AND VENUS

In considering the problem of the possibility of life in our solar system it is but natural that we should turn our attention to our closest neighbours—Mars and Venus. Mars revolves around the Sun at a somewhat greater distance than the Earth (the radius of Mars' orbit is 228 million kilometres) and it makes a full revolution in 687 terrestrial days; Venus is somewhat nearer to the Sun (the radius of its orbit is 108 million kilometres) and the period of its revolution is 225 days. Both planets are surrounded by atmospheres, may have water in a liquid state, and, at first sight, life in some form is, therefore, possible on them.

We shall first state what is known of the nature of Mars. Observations of this planet date from the end of the 17th century; C. Huygens was its first systematic observer.

Very valuable observations of Mars were conducted at the end of the 18th and the beginning of the 19th centuries by J. Schröter, an amateur astronomer, in the small German town of Lilienthal. Schröter had at his disposal the finest telescope of the time with a 23-cm lens noted for its excellent optic qualities (such a telescope would be perfectly suitable for similar observations even today). Schröter made careful drawings of the contours of the different details on the planet's disk, especially its dark spots or seas, as they were later named by Schiaparelli. Schröter himself believed these spots to be clouds and tried to study their possible displacements in order, thus, to determine the force of the winds in the planet's atmosphere.

The experience of the observer and his numerous observations made the material obtained very valuable. By comparing Schröter's drawings with modern drawings and photographs and identifying the same details on them it is possible to determine with great accuracy the period of Mars' rotation about the axis and subsequently to judge the constancy of this period; at the same time it is possible to conclude to what extent the dark formations on Mars are permanent. Generally speaking, the details observed on Mars belong, as a rule, to its solid surface, while different cloud formations are encountered rather seldom and are of a transitory nature. As far as the dark spots—the seas—are concerned the opinion prevails that they do not change generally and, in all probability, characterize lower and more humid regions of the planet. This is quite true. However, already Schröter's observations, which were conducted nearly 150 years ago, have shown that big changes in the contours and distribution of the seas can sometimes also take place on Mars. Thus, for example, the vast dark region in the shape of an acute triangle observed by him and represented in 16 drawings (longitude 225° and latitude 15°) during 1798-1800, now no longer exists. This region was located on the edge of the modern Mare Cimmerium and for a period of approximately 20 years was one of the objects on Mars most accessible to observation.

Only sporadic observations of Mars, which did not reveal anything essentially new, were conducted after Schröter during the first decades of the 19th century. A new epoch in the study of this planet, undoubtedly, began with the work of Schiaparelli who observed Mars systematically and for a long time under the clear and stable sky of Milan with a fine 21-cm lens telescope. In 1877, while systematically observing Mars for the purpose of charting it, patiently waiting for the atmospheric vibrations to cease and for rare moments of stable representations, Schiaparelli suddenly noticed a straight thin line running through the reddish desert and connecting two neighbouring maria. Continuing his observations he was able to register a number of such thin dark lines of a regular contour which invariably connected separate dark spots on Mars' surface. Sometimes they crossed and the point of their intersection always appeared as a roundish dark spot, as some sort of "oasis." Several months later Schiaparelli reported in the press his discovery of these lines—so-called canals which gave rise to animated discussions and roused extensive interest in the study of Mars. He also established that the dark spots were really of different hues, from brown to green in various combinations, that the maria in the equatorial zone were much darker than the ones closer to the poles and that these formations could in no way be regarded as aqueous surfaces, as was formerly thought, particularly by Flammarion. The continents or deserts on Mars are also notable for their different colouring from yellowish to red, though they are much more uniform than the maria. Schiaparelli, furthermore, discovered that the canals—the thin, more or less clean-cut lines—in some epochs appeared double sometimes several hundred kilometres apart. For nine years nobody could confirm the existence of the canals though more powerful instruments than Schiaparelli's telescope were used. Their existence was confirmed only in 1886 by the English amateur astronomer S. Williams with the aid of a small 15-cm telescope. Soon afterwards the canals were noticed by the French astronomers Perrotin and Tollon through the 75-cm refractor of the Nice Observatory.

Since then many other observers have also begun to notice the canals though with different degrees of clarity. At any rate the existence of the canals could no longer be doubted, but their nature appeared mysterious. It is easy to understand that after their discovery the canals on Mars began to be regarded as incontestable proof of the existence of highly developed beings who had built them, apparently for irrigation purposes, as waterways through arid deserts.

It should be remembered that the Laplace cosmogonic hypothesis, which enjoyed universal recognition at the time, maintained that Mars as a planet was older than the Earth. It, therefore, seemed likely that the living beings on Mars had reached a higher level of development than terrestrial mankind. Schiaparelli himself wrote about the canals: "Their strange appearance, their absolute geometrical regularity prompted some people to believe they had been built by intelligent beings, inhabitants of this planet. I do not deem it possible to contest an assumption which is not at all unlikely."

It goes without saying that these discoveries made by Schiaparelli and other scientists excited enormous interest and impelled many astronomers to observe Mars systematically. P. Lowell, an American diplomat, took a particular interest in Mars. He immediately started a correspondence with Schiaparelli and then built a special observatory in Flagstaff, Arizona (U.S.A.), to observe Mars. The observatory was supplied by a large refractor with a 60-cm lens. The visual and photographic observations, conducted by Lowell and his associates for a number of years made a valuable contribution to the study of Mars. Lowell not only fully confirmed the existence of the canals discovered by Schiaparelli, but also discovered new ones. He showed that the canals crossed equally the deserts and the maria with their intersections in the maria frequently forming small, round "oases." Some of these canals could be seen on photographs obtained in Lowell's observatory. Separate canals were also discovered by G. Tikhov in 1909 on photographs taken in Pulkovo with a 75-cm refractor during the favourable opposition of Mars. Lowell carefully investigated the seasonal changes on Mars which, according to him, consisted in the fact that after the polar snows had begun to thaw the maria adjoining the polar cap started growing darker and changing colour with the darkening gradually spreading towards the equator and even crossing it into the other hemisphere.

Lowell's observations, which had confirmed the regular geometrical form of the canal system, led him to the firm belief that they had been built by Martian engineers and were incontrovertible proof of the high technical culture of this planet's inhabitants. According to Lowell the Martian canals were artificial structures designed for transferring water from the melting polar caps to the equator. He even calculated the capacity of the pressure system which the Martian engineers had supposedly built and found it was at least 4,000 times as great as that of the Niagara Falls. All these considerations of Lowell's are expounded in his books *Mars as Abode of Life* and *Mars and Its Canals*. Broad sections of lovers of astronomy were fascinated by these statements of the existence of thinking beings on Mars. Various means of establishing communications with the inhabitants of Mars were repeatedly proposed.

But despite the fact that the Martian canals were discovered approximately 80 years ago and were observed during 36 different oppositions of this planet there is as yet no general agreement on their nature. The greatest difficulty in the solution of the problem lies in the fact that even experienced observers are not always able to agree on their observations of Mars with the use of the very same telescopes. Maunder's well-known experiments proved that such objects as canals which are nearly on the borders of visual perception and are caught only during the rare moments when the atmosphere is calm can really be complex and irregular small details even absolutely isolated. Only the widest canals can be registered photographically. There can be no doubt that the finest canals had never been photographed by anybody since the least vibration of the air must completely mar the picture even if they actually existed. The solution of the problem of the nature of the Martian canals, thus, depends in large measure on the resolving power of the telescope and the conditions of observation as well as the experience of the observer and his ability objectively to evaluate the data of the observations.

B. Lyot, outstanding observer and designer of ingenious and accurate optic instruments, with the aid of which he himself and his associates observed planets, including Mars, has contributed a great deal to the study of Mars and its canals. Recently, in the Alpine observatory Pic du Midi, located at an altitude of 3,000 metres, they used a telescope with 60-cm lens which enabled them to discern the details on the surface of the planet as though it had been brought 300 times as close to the observer. The telescope with the 20-cm lens, which was used by Schiaparelli and other observ-

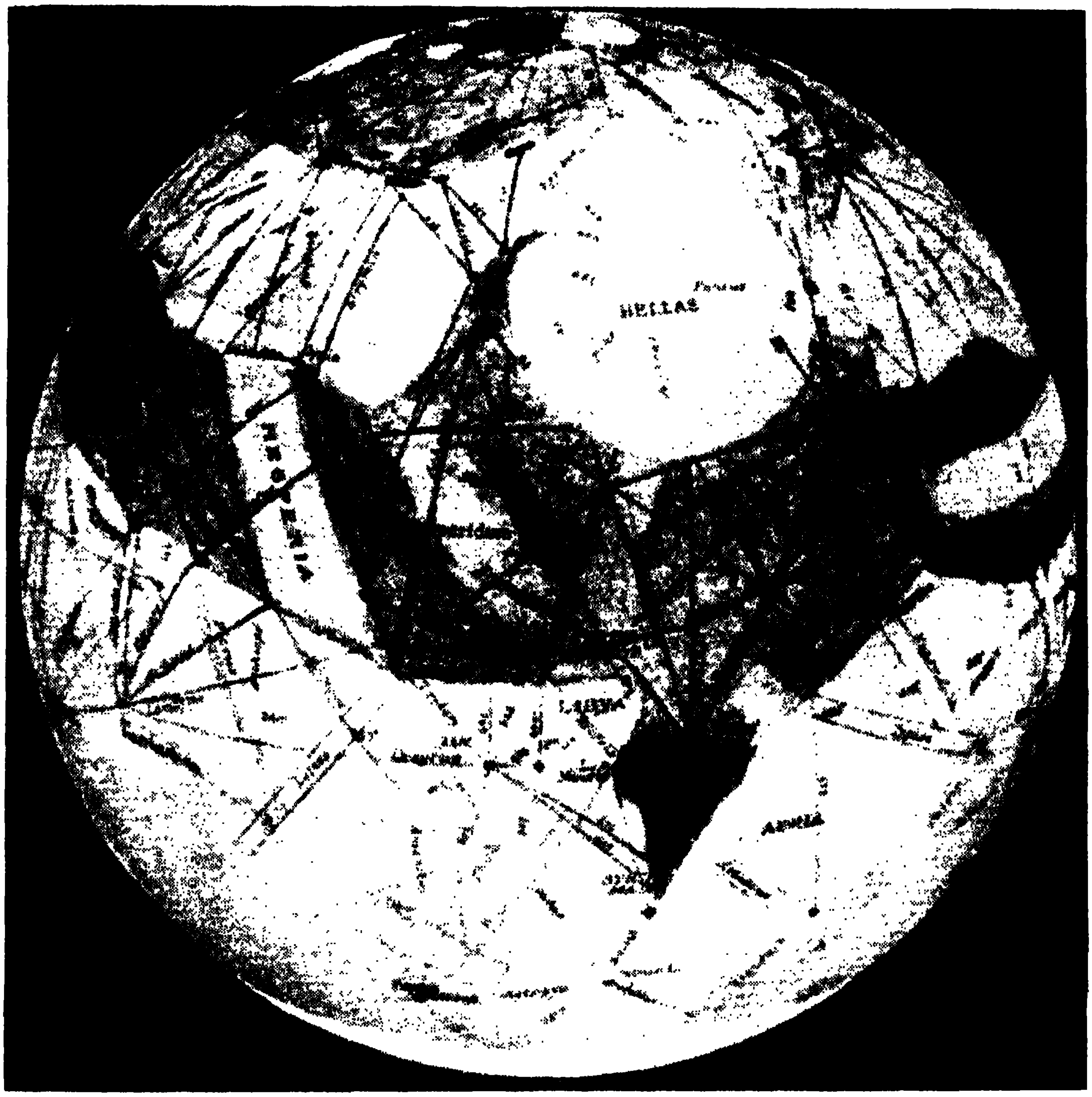

Fig. 38. Mars after Lowell

ers, can bring the object at best 100 times as close. This magnification is possible only when the atmosphere is ideally calm. As a matter of fact, atmospheric conditions frequently prevent good visibility. To the usual diffraction, which distorts the image, there is also added the phenomenon of diffusion connected with a disturbance of the air, and its influence is usually increased with the use of larger instruments. The effective resolving power of a telescope may, therefore, not only fail to grow, but, on the contrary, diminish with the increase in its size depending on the atmospheric variations. The success in observing planets depends primarily on the choice of a sufficiently favourable place corresponding to the correct arrangement of the atmospheric layers in the direction of the line of sight, i.e., absence of a turbulent mixing of the air and absence of local air currents which result from an uneven heating of the soil and of the details of the relief of the area itself, etc. It goes without saying that all convective air currents within the tube of the telescope, caused by temperature fluctuations, must also be eliminated. Thus, the observation of planets requires extreme caution which is not necessary in observing stars or extensive nebulae. It must also be taken into account that planets cannot be well observed when they are low over the horizon because in this case the fine vibrations of the images increase. In addition it is necessary that the apparent dimensions of the planet itself be large enough which is possible only at the time it is closest to the Earth.

Mars is usually closest during its oppositions which recur approximately every 26 months. But since Mars' orbit is an ellipse it happens to be at different distances from the Earth during its various oppositions—within 35 to 62 million miles. The most favourable oppositions occur every 15 years when Mars is invariably in the southern hemisphere and, besides, in summer. Thus, for example, a favourable opposition occurred on July 2, 1954. Its apparent diameter constituted approximately 70 per cent of the possible maximum. In

September 1956, Mars was drawn closest to the Earth and its apparent diameter was 97 per cent of the possible maximum. The next time Mars will come so close will be in 1971. During each of the oppositions Mars can be observed

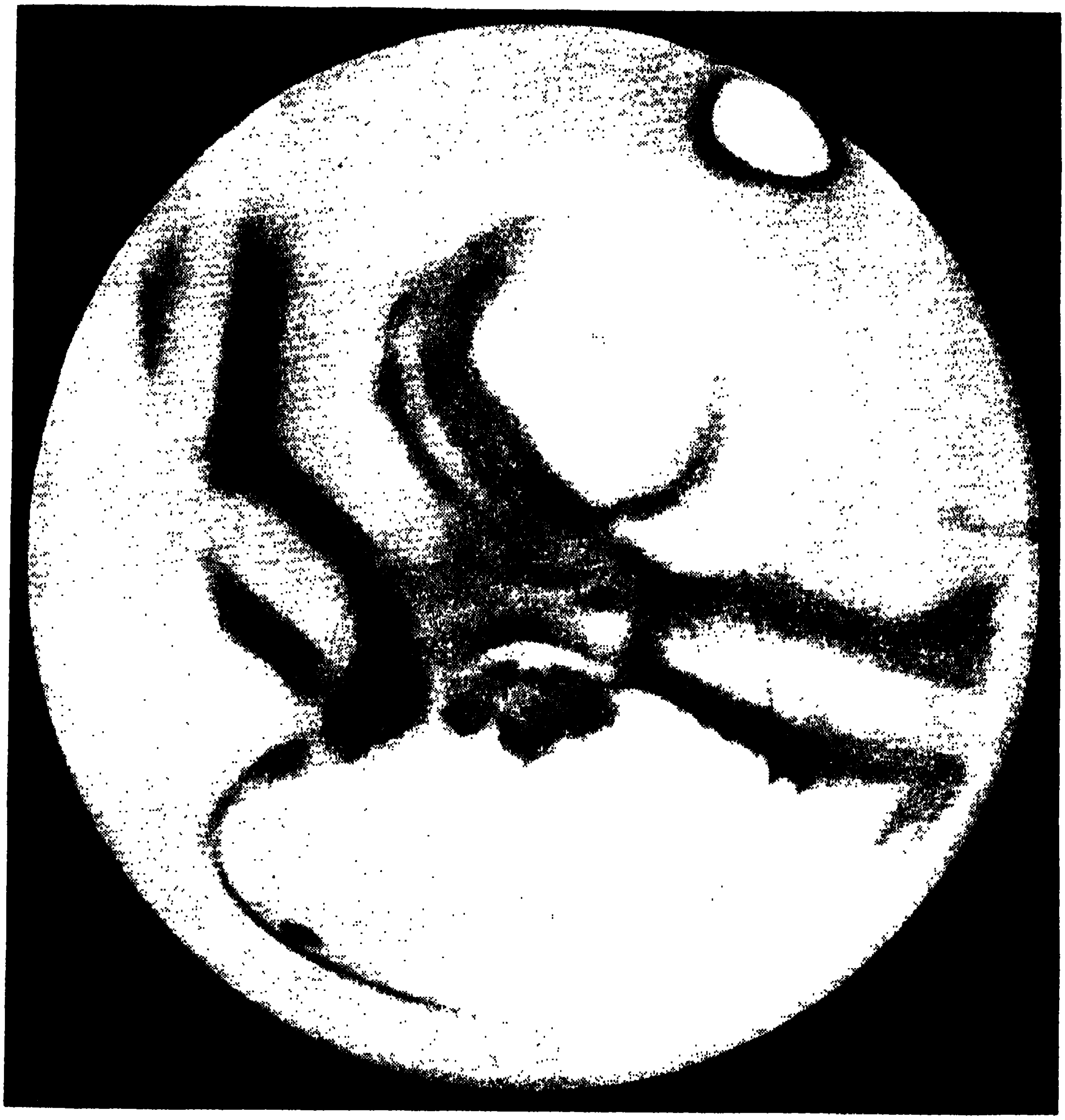

Fig. 39. Mars after Antoniadi

only for two or three months. Unfortunately its position during the favourable oppositions in the southern hemisphere is too low over the horizon for the observatories of the northern hemisphere. Thus, for example, for the Pulkovo Observatory, located under latitude 60°, Mars during its big opposition in 1909 was at a low altitude over the horizon—

only 26°. The best study of Mars requires an observatory somewhere in the southern hemisphere of the globe in order that the planet may not leave the zenith for more than 30°

With a 60-cm lens telescope it is possible under extremely favourable conditions to "bring" the planet 300 times as close. This means that even during the closest approach of Mars to the Earth its equivalent distance is conditionally reduced to 170,000 kilometres at best. But this is achieved very seldom, and under ordinary good atmospheric conditions Mars appears the way it would appear to the naked eye at a distance of at least 300,000 kilometres. The smallest detail that can be discerned on the planet under these circumstances must measure at least 100 kilometres. It stands to reason that with the quality of the picture altering from moment to moment and from night to night the observers, depending on their experience and skill, may divine the presence of certain details on Mars which they inevitably stylize, draw in a sufficiently distinct and definite form and then put on their maps. This is, for example, the way Lowell did firmly believing in the existence of a geometrically regular network of canals. His drawings on which Mars is mottled with numerous canals in the form of finest lines in no way represent the appearance of this planet at some definite moment of observation; it is always a summary of odd sketches each of which contains only a small number of such details. On the other hand, Antoniadi, also a highly conscientious observer and artist by profession, who worked with the big telescope of Meudon Observatory, never saw Mars covered with a geometrically regular network of canals, though he discerned many more separate small details, especially on the surface of the Martian maria, than Lowell did. It is clear that in order to ascertain the true picture of Mars it is necessary to increase the resolving power of telescopes. This was in some measure accomplished by Lyot and his associates who have, undoubtedly, made the very best visual observations of Mars.

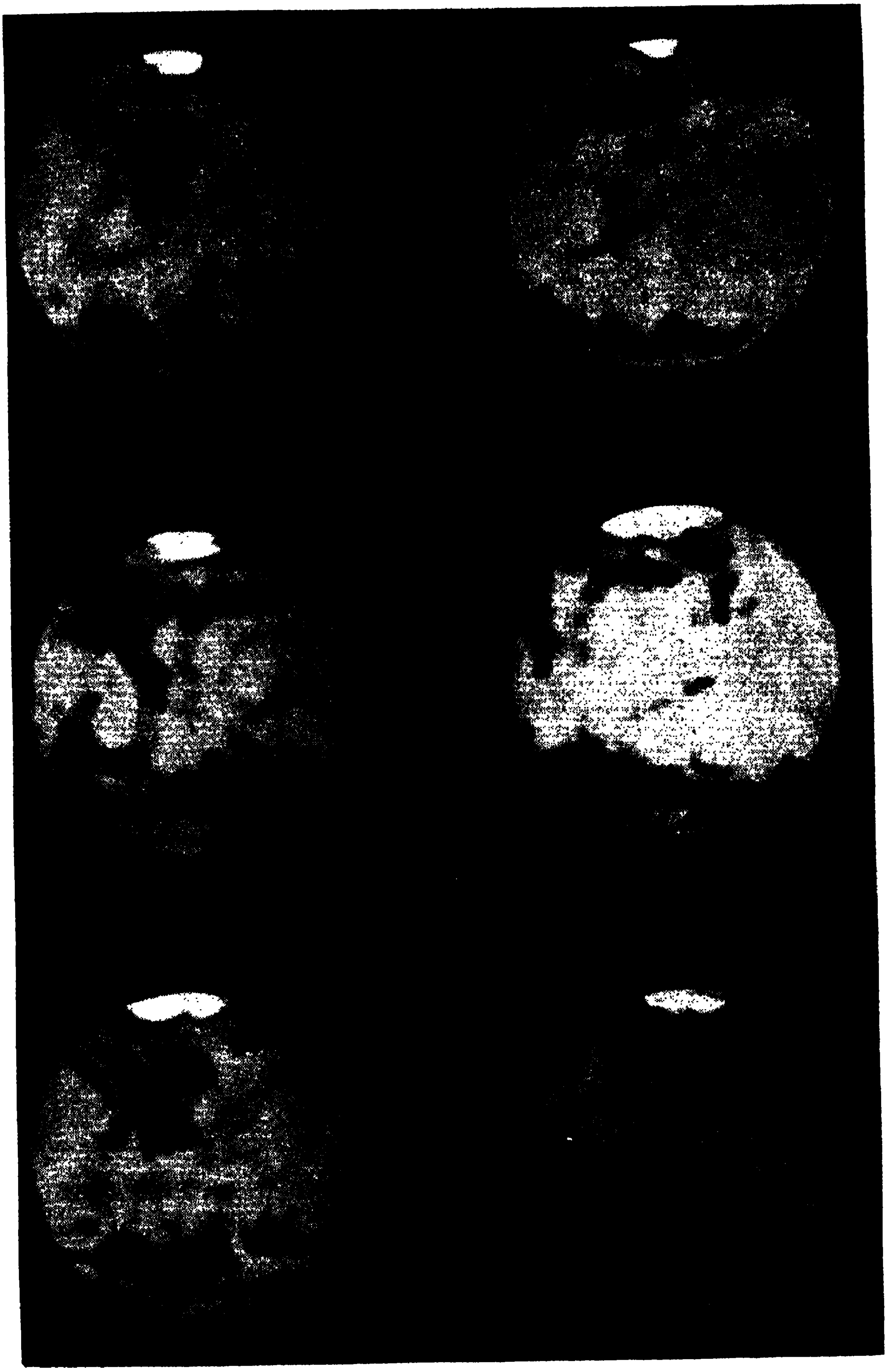

Fig. 40. Mars after the drawings by Lyot

The results they have obtained on the Alpine observatory Pic du Midi may be characterized as follows. The dark maria, which are usually portrayed as uniform areas, really have an extraordinary complex structure. They have numerous small spots irregularly distributed and differently coloured. The distribution and appearance of these small spots change with each opposition, and after all, this conditions the changes in the appearance of the entire maria in which they are located. Apart from the seasonal changes, which occur quite regularly and naturally, mention should be made of changes of an epochal nature, which sometimes occur slowly and gradually, but in other cases take the form of sudden cataclysms at once changing the character of the area.

A. Dollfus cites a number of examples of these changes on Mars based on his observations in the Pic du Midi Observatory during 1941-1952. He has, thus, for example, published a series of drawings showing sharp changes in the region of Trivium Charontis since 1943. Two clearly visible, distinct parallel lines running in a nearly meridional direction for a distance of approximately 500 kilometres emerged from a dark spot named Trivium and ended in small bulges. This phenomenon could still be traced in 1946, though it appeared dimly, but it has completely disappeared since 1948, though other and finer details have remained nearly unchanged. The well-known Solis Lacus is an example of these changes on an even greater scale. In Schiaparelli's time it appeared as a quite sharp and round formation whence it received its name. But since the beginning of the 20th century Antoniadi and later all subsequent observers have drawn it as a totality of very irregular spots generally elongated in a parallel. According to A. Dollfus and other observers the dark spots on Mars are subject to constant and considerable changes clearly manifest when the drawings or photographs obtained at intervals of ten or more years are compared.

As to the nature of the canals we can now quite definitely assert that they are not continuous and geometrically regular formations. The canals can generally be divided into three categories: relatively wide pale bands with eroded edges; narrow, regular lines but with somewhat indefinite contours, and canals proper—thread-like, black and appearing only now and then, but usually invisible. It has been found that in very good pictures all these types of canals as such disappear. In their place there is an aggregate of small details, differently coloured, irregularly shaped and irregularly distributed which quite resemble the details present in the dark maria. In very good images and greatly magnified these details can be studied individually. But if the images grow worse during the same night continuous regularly shaped strips immediately reappear in place of the small details and the largest of these strips can be photographed. These conclusions were confirmed by N. Barabashev on the basis of his systematic observations of Mars at the Kharkov Observatory during 1920-1950. The representation of the canals as bands or lines is, thus, simply a stylized unification of the small and irregular details found in their place. As to the canals in the form of finest lines drawn by P. Lowell, they are now regarded as a purely subjective phenomenon

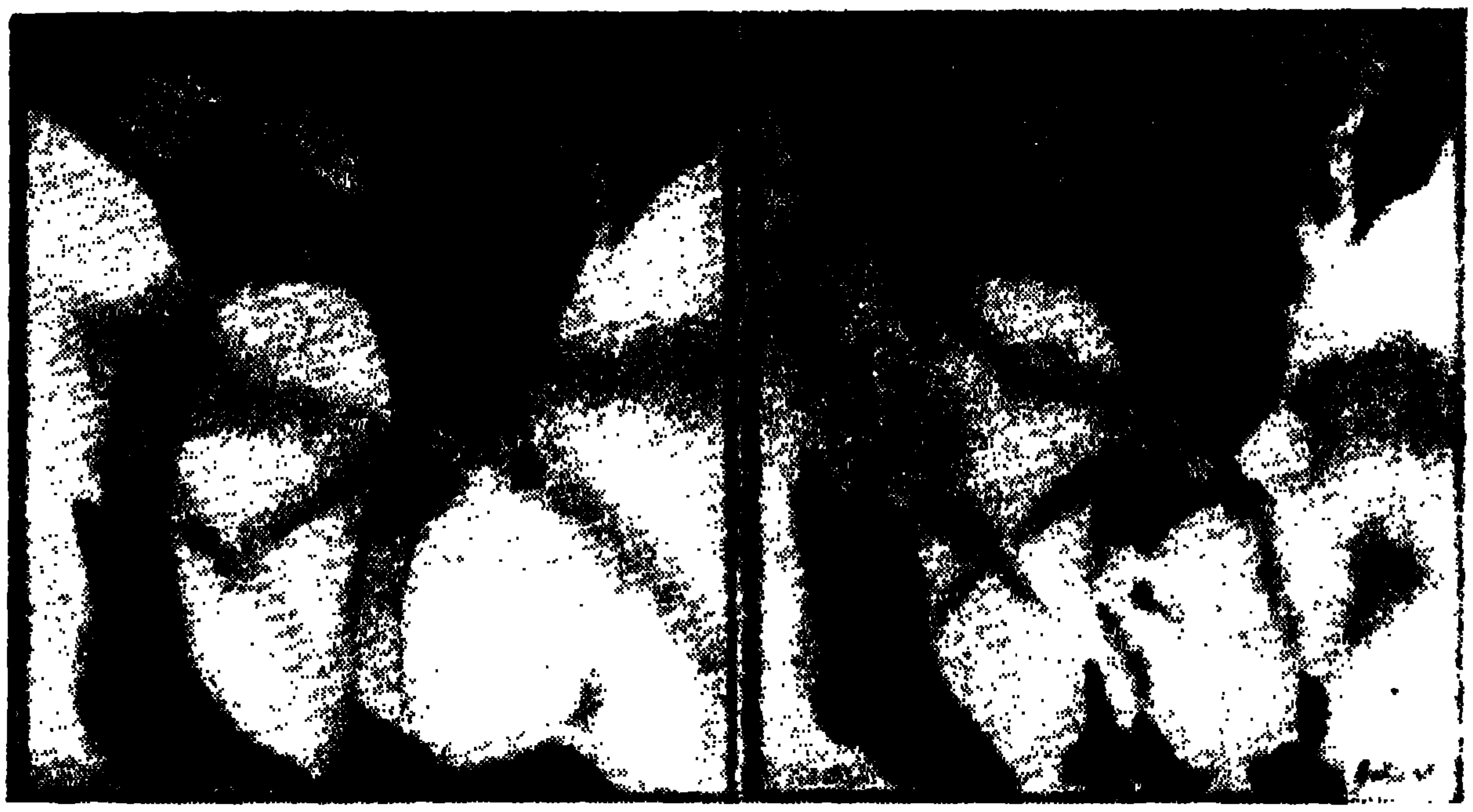

Fig. 41. The canals on Mars after Dollfus; (left) mediocre and (right) good pictures

peculiar to the eye when it works on the borders of perception. Incidentally, this is clear at least from the fact that the canals in Lowell's drawings are many times as narrow as he could have seen in his telescope.

We may, thus, assume that the so-called canals are made up of the same small details that abound on the surface of the maria and that their general systematic distribution is, apparently, connected with certain structural peculiarities of Martian soil.

It would be interesting to pose the question as to the Martian relief. No sharp changes in the relief on Mars can be discerned. There are no data in favour of high mountains on the planet. The simplest way to judge the unevenness of the planet's relief is by the melting of the polar snows. Observations of this type are quite instructive.

When the polar snows melt and the size of the polar cap diminishes rapidly we can observe separate notches in the contour of the latter and formations of growing islands which appear in the same places every time. Separate regions, already free from snow, sometimes turn white again for a short period, apparently, due to night hoar-frost. Figure 42 shows the nature of seasonal changes in the polar cap according to A. Dollfus' observations. It is obvious that the local temporarily growing isles of the polar cap are at a considerable altitude above the general level of the planet. This altitude can be approximately estimated if we take into consideration the temperature gradient in Mars' atmosphere, which, according to Hess, is approximately 4°C per kilometre of altitude. It turns out that near Mars' North Pole there are separate plateaux about one kilometre above the general level of the surface. It is quite possible that similar differences in the levels also exist in other regions of the planet. This circumstance renders the existence of a geometrically regular network of canals even more improbable. At the same time Lowell's assumption that the network of canals serves as a water-supply system for feeding water from the polar regions to the different other latitudes and even to the equator is also wrong since the water resources in the polar caps are quite negligible.

The idea that Mars is inhabited by intelligent beings, widespread at the end of the 19th and in the beginning of the 20th centuries mainly because of Flammarion, Schiaparelli and Lowell, is no longer accepted today. Nevertheless, the assumption that organic life, for example, vegetation, exists on Mars causes no objections. The principal argument in favour of the existence of vegetation on the planet is the changes in the colouring and form of the maria observed on it.

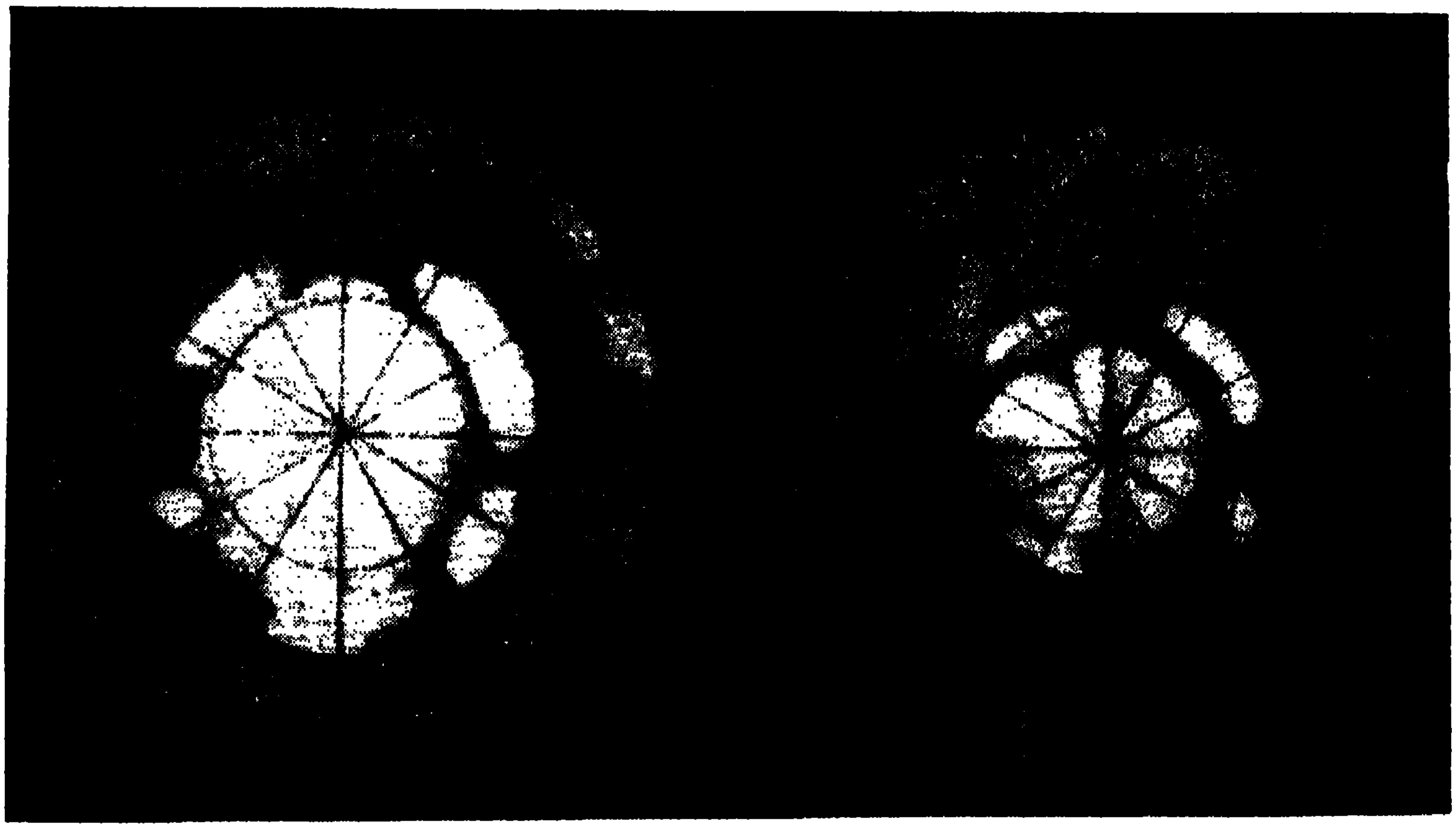

Fig. 42. Melting of polar snow on Mars

Thus, for example, having discovered considerable changes in Solis Lacus on Mars Antoniadi wrote in 1924-1926: "Some sort of dark-green substance has covered the reddish regions over a large area." The testimony of this observer who specially studied Mars for many years carries considerable weight. Antoniadi believed that vegetation developed on Mars before his eyes. The enormous majority of investigators is also of this opinion. In our country these views have become widespread mainly because of G. Tikhov's works (*The Planet Mars* and *About Vegetation on Mars*).

G. Tikhov began his observations of Mars as early as 1909, when he secured photographs of this planet in different rays of the spectrum with the aid of the 75-cm Pulkovo refractor. During 1918-1920 Tikhov continued to study Mars visually in Pulkovo by means of a 38-cm refractor and discovered regular changes in colouring connected with the Martian seasons. He is one of the chief propagandists of the existence of organic life on Mars. G. Tikhov's views were expounded by various authors in numerous lectures, pamphlets and popular-science books.

It should be noted that the idea that Mars is inhabited has gained wide popularity abroad. Thus, for example, Spencer-Jones in his book *Life in Other Worlds*, published in a Russian translation in 1946, makes the following statements: "On the planet Mars ... we really encounter an almost definitely established existence of a vegetative cover.... I believe we must see in Mars a world with life dying out. The vegetable forms, which can now continue their precarious existence on the planet, are doomed to extinction in the very near future...." The last sentence, which sounds rather pessimistic, reflects an evaluation of the influence of the Martian physical conditions, whose severity is gradually ascertained, on the existence of organic life.

Perfectly objective physical methods of investigation —thermoelectric, photometric and polarimetric—have been used in studying Mars in the last 30 years, whereas formerly the planet had been studied only visually, and, as a rare exception, more or less felicitous photographs reproducing, at best, only the principal details were made. In the U.S.S.R. the systematic observations of V. Sharonov and, especially, N. Barabashev were of considerable importance.

In general, a thorough study of the physical conditions on Mars is conducive to a gradual rejection of the former passions despite the widespread desire to see the planet as a carrier of life similar to the Earth. Nevertheless, the idea of life on Mars is most widespread among astronomers today irrespective of their ideological tendencies. Modern idealists do not differ in this respect from the former ones. Thus, for example, the British astronomer Smart in his book *The Origin of the Earth*, published in England in 1951, after making a declaration of the "cosmic aim" and the "divine creator," writes that life is gradually becoming extinct on Mars.

In this respect there is no difference between Smart, the idealist, and Spencer-Jones, who occupies a materialist position. Both of them acknowledge the existence of life on Mars in some more or less primitive form. The well-known idealist James Jeans who was sceptical of the idea of life on Mars nonetheless believed that life might be widespread in the Universe generally. In his book *Movements of Worlds* he wrote: "It is possible that other stars also have inhabited planets in their families" (p. 58).

Thus, the attitude to the problem of organic life in the other worlds alone does not in our epoch fully determine the nature of the scientists' philosophical views and does not always serve as a cause for ideological struggle. The private problem of life on Mars, despite the opinion of some investigators, is even of lesser importance as regards ideology.

But the idea that Mars is inhabited by higher organisms, which is at variance with facts, leads to unhealthy sensations even today. The stories about the Tungus Meteorite claimed by some Soviet writers to have been an inter-planetary (Martian) ship, wrecked in landing, may serve as an example of this.

* * *

We shall now briefly dwell on the problem of the physical conditions on Mars as they appear in the light of modern data. A general summary of these data was recently made by de Vocouleur in his book published in 1951.

Mars has a noticeable, though quite rare, atmosphere with a "violet" layer (5-25 kilometres high), which vigorously absorbs in the blue, violet and ultra-violet parts of the spectrum, located in its lower parts. Its nature is as yet unknown; it may consist even of minutest crystals of carbon dioxide, but, most probably, of crystals of ice. This layer is not quite uniform and sometimes forms visible gaps.

There are two types of clouds in Mars' atmosphere. The lower yellow clouds are, apparently, a diffuse sheet of sand dust raised by winds from the planet's soil. Observations of many investigators show that this dust is capable of obscuring details of the surface for a considerable length of time. The clouds of the upper tier (18-25 kilometres) are violet-coloured, transparent and invisible in the red rays, but very well seen in the blue and, especially, violet rays. This is why in the violet and ultra-violet rays Mars looks entirely different from what it does in the usual visual and, particularly, in the red rays of the spectrum. The nature of the upper clouds hardly causes any doubts now. In their properties they are completely analogous with the silvery terrestrial clouds which are observed at an altitude of 80 kilometres, i.e., precisely at the altitude with the lowest temperature. The silvery clouds, as has been shown by I. Khvostikov, consist of finest crystals of ice, and their presence at precisely this altitude can be determined on the basis of the distribution of pressure and temperature in the terrestrial atmosphere. Such clouds cannot give any precipitation either under the terrestrial conditions or on Mars, and especially on the latter.

The atmospheric pressure and, consequently, the total atmospheric mass on Mars can be determined on the basis of purely photometric observations conducted with various light-filters. Such work was done in the U.S.S.R. by V. Sharonov and N. Sitinskaya, as well as by N. Barabashev, B. Semeikin and Timoshenko. First the aerosol and purely gaseous constituents of the atmosphere are divided and then the value of the latter, which conditions the atmospheric pressure, is determined. It is also possible to use the determinations of the degree of polarization at different points of the planet's disk. This method was developed and used by Lyot and his pupil Dollfus. Finally, Hess has shown that if the force of gravity is known the atmospheric pressure on Mars' surface can be determined by studying the altitude of cloud condensation (known, for example, from Antoniadi's observations) and the temperature on its surface (established by Coblentz and Lampland). The mean value of the atmospheric pressure on the level of Mars' soil corresponding to 65 mm mercury or 87 millibars was obtained from ten different determinations. (To make direct comparison with terrestrial conditions possible it was assumed during the calculations that the mercury was under the action of terrestrial rather than Martian gravity). Under this pressure water boils at 43°C. Since the temperature on Mars' surface is always lower the water on it can be in a liquid state.

On the basis of the known force of gravity we can find that the pressure in Mars' atmosphere diminishes ten-fold with each 40-kilometre rise. The terrestrial and Martian atmospheric pressures are equalized at an altitude of 28 kilometres. At higher altitudes the atmospheric pressure on Mars is greater than it is on the Earth.

Observations have shown that the atmospheric circulation on Mars is very much like that on the Earth. But the velocity and distribution of the winds, determined by the displacements of cloud masses, are not well enough known as yet.

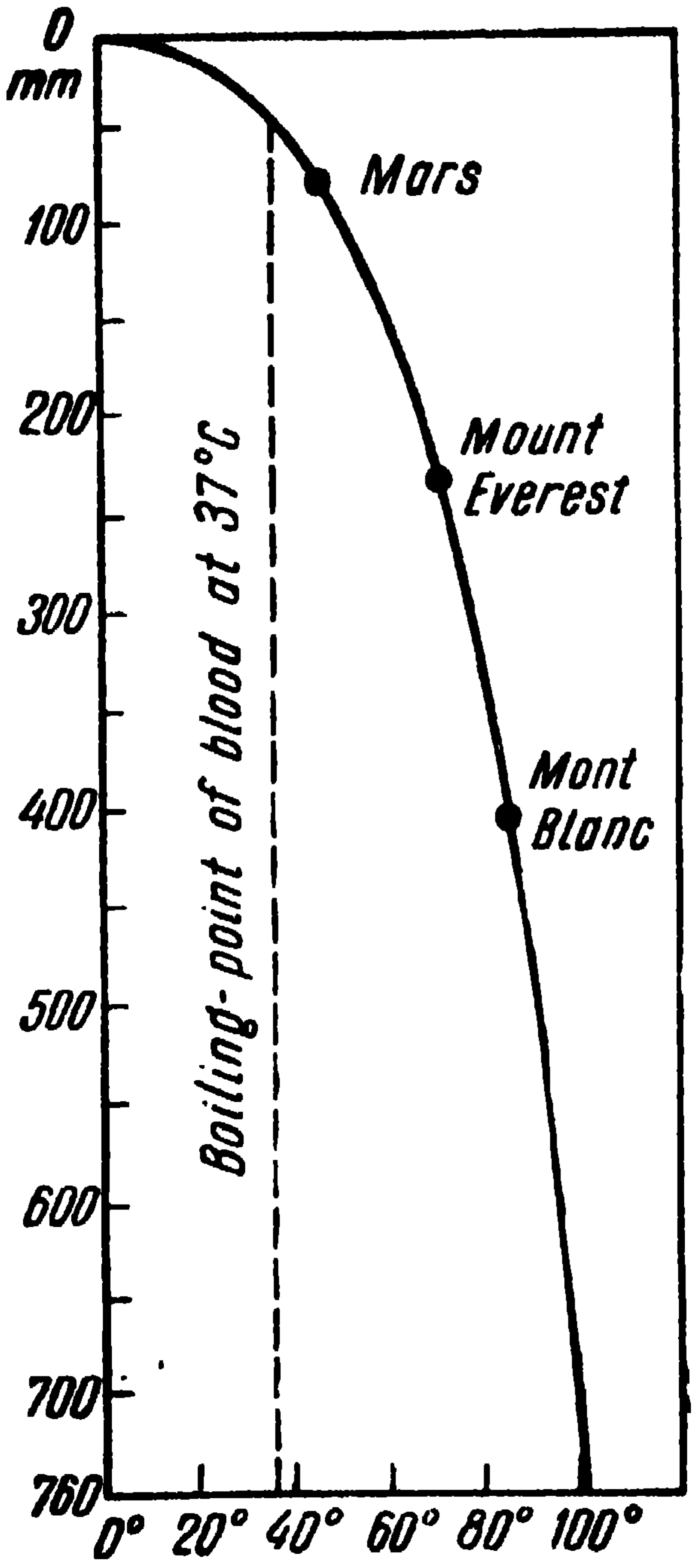

Fig. 43. Boiling-point of water on Mars compared with the high mountains on the Earth

The question of the chemical composition of Mars' atmosphere is very important. It has been possible directly to discover only carbon dioxide in a quantity only double that of the Earth. No oxygen has been found at all. The powerful modern spectrographs can confidently separate the oxygen lines on Mars from those in the terrestrial atmosphere. With the perfect modern scientific methods these lines could have been discovered even if there were 1,000 times as little oxygen on Mars as there is on the Earth. It has been impossible, however, to discover the least trace of oxygen on Mars. It is very possible that there is no oxygen on Mars at all, because it can be hardly supposed that so extraordinarily active a gas could exist in an atmosphere in a negligible quantity. At any rate, on Mars there must be less than 0.1 per cent of the amount of terrestrial oxygen. This upper limit is invariably lowered the more accurate the observations. There is so little water vapours in Mars' atmosphere that it is also absolutely impossible to discover them spectroscopically. Investigators have also been unable to find any other gas constituents.

What then can the principal constituents of Mars' atmosphere possibly be? In considering this problem it is natural to proceed, firstly, from the general abundance of different elements in nature and, secondly, from the composition of the terrestrial atmosphere. It is obvious that there are hardly any of the lightest gases—hydrogen and helium (very plentiful in the Universe)—just as they are rarely encountered in a free state on the Earth. Nor can we expect on Mars any neon, extraordinarily widespread in nature, since this inert gas is undoubtedly a primary gas and is hardly encountered even in the terrestrial atmosphere. Argon with its atomic weight 40, constituting a little less than one per cent of the terrestrial atmosphere, is a product of radio-active disintegration while the activity of this process on each planet is approximately proportional to its mass. It may be assumed, all other conditions being equal, that the amount of this gas over a unit of surface must be approximately proportional to the radius of the planet. For this reason there is, apparently, hardly any argon on Mars either.

Nitrogen must, evidently, be the principal gas in the Martian atmosphere. This gas is very widespread in the Universe and is plentiful in the terrestrial atmosphere. On the Earth it is liberated as a result of various tectonic processes, partly in compounds with other elements and partly in a free state. A. Fersman, for example, noted a high content of nitrogen in the mud-volcanoes and the cold fumaroles of the Kamchatka volcanoes. At a high temperature nitrogen can be liberated in a pure state. Such liberation occurred, for example, from the bore-hole in the dunite massif of Nizhny Tagil, where the liberated gases consist of 57 per cent N_2, from the fumarole of the Avachy Volcano on Kamchatka, where the volume of nitrogen constitutes 24 per cent of the liberated gases, and from a bore-hole in the State of Utah (U.S.A.), where the daily debit of liberated nitrogen exceeds 500,000 cubic metres at a pressure of 50 atmospheres (content about 1.1 per cent). The highest content of nitrogen in gas currents was registered in Emba Tyulyus (100 per cent and rare admixtures), in Belokurikha in the Altai and elsewhere. In addition, there is a large number of springs of water with nitrogen, especially in the central and northern parts of the U.S.S.R. Nitrogen in a pure state can also be liberated into the atmosphere from the soil by certain bacteria—denitrifiers. It is possible that nitrogen is partly of a biogenic origin, as Academician V. Vernadsky supposed, and partly of a tectonic origin, as it is actually observed. Getting into the atmosphere nitrogen, as a relatively inert gas, can remain in it for an indefinitely long time especially if there are no micro-organisms to consume it. It can, therefore, be assumed that at least 98 per cent of Mars' atmosphere is nitrogen. The remaining two per cent are made up of argon, carbon dioxide and small additional admixtures.

As Vocouleur observes, the atmosphere of this composition actively absorbs the extreme ultra-violet rays. As a result of photochemical dissociation of nitrogen all waves less than 0.17 micron long are absorbed; carbon dioxide absorbs the rays at a wave-length of 0.20 microns; but the violet layer in Mars' atmosphere, very probably, absorbs a considerable part of the rays in the interval of 0.35-0.40 microns.

Compared with the Earth, clouds are an extremely rare phenomenon on Mars, but over the entire surface of the planet as a whole they can be observed quite frequently, nonetheless. Thus, for example, N. Barabashev was able to observe one or two such formations most of the times. Solid precipitation occurs much rarer. White clouds form mainly near Mars' terminator, i.e., actually on the edge of its disk where the temperature is much lower and the conditions for their condensation are more favourable.

The grey diffuse clouds, which various observers ascribed to ejection of gases and fine dust during volcanic eruptions, are observed much rarer. During the very favourable oppositions in 1909 and 1911 Antoniadi often observed from the Meudon Observatory that the Deucaleon Regio was veiled by greyish cover which he ascribed to vulcanism. T. Saheki describes a number of strange grey clouds which were observed on Mars at different times during 1950-1952 by members of the Martian section of the Eastern Astronomical Association of Japan. These formations sometimes become diffuse and occupy an area with a diameter of nearly 1,000 kilometres and rise, according to T. Saheki, to an altitude of 100-200 kilometres above the level of the planet's surface. If they turn out to be near the edge of the disk they present a definite elevation as compared with the general level, which is clearly seen on the drawings made. Their formation, apparently, does not depend on the distribution of temperature on the surface of the planet. If it could be established that their appearance is connected with definite details on the surface the assumption of vulcanism on Mars would receive considerable observational grounding. At any rate, formation of such cloud masses, comparatively compact and consisting, judging by their colour, of quite large particles, at an altitude of hundreds of kilometres does not seem possible. On the other hand, if on the Earth abounding in water and on the Moon where there is no water or air vulcanism manifested itself very actively in the past and manifests itself weakly now, there are no reasons to deny similar phenomena on Mars, which in its nature is intermediate between the Earth and the Moon.

Mars' climate can be characterized as follows. The temperature of the surface of the planet is lower than the terrestrial on the average by 30-40°C. At the equator the mean temperature of the soil is —10, —20°C, in the polar regions —60°C. The amplitude of daily temperature fluctuations is more than 50-60°C with the maximum reached at about one o'clock in the afternoon. The amplitude of annual fluctuations is taken at about 120° at the South Pole, about 100°C at the North Pole, 50°C in the intermediate regions and approximately 30°C at the equator.

It is essential to note that in the daytime the temperature of the dark spots is higher than that of the light regions by approximately 10-15°C. The highest soil temperature in the equatorial regions in the daytime is 10°C, in the Martian deserts it is 20°C and in the so-called maria it is 25°C. The temperature of the air near the surface is much lower than the temperature of the soil and always stays below zero. In the daytime this difference constitutes at least 30-40°C and is, probably, evened out at night. Intensive convection with a rapid drop in temperature as the altitude increases must be developed in Mars because of this. It may be assumed that at the altitude of 15 kilometres the temperature drops to —80, —100°C.

The temperature of the clouds of the first type (yellow) and of the polar fogs which absorb the radiation of the surface is no higher than —70, —80°C which corresponds with the probable temperature of the Martian atmosphere at an altitude of 15-20 kilometres. The clouds of the second type, analogous to our silvery clouds, have an even lower temperature.

The polar caps on Mars are composed mainly of hoarfrost with a very low temperature. The thickness of these caps is unknown, but it must be insignificant—about a frac-tion of a millimetre—as can be judged by the rate of their thawing. The non-melting central part of the polar caps consists, in all probability, of ice, but it cannot be more than a few centimetres thick either.

According to modern spectroscopic determinations the total content of water in the Martian atmosphere is less than 0.001 of the water content on the Earth in winter over mountains 2,000 metres high. Simple calculations show that if we take the relative humidity as 50 per cent at a temperature of —10°C, which approximately corresponds to our mountain conditions, absolute humidity will equal only 1 mm. Hence, according to the well-known formula, the content of water in the entire atmosphere in a column of air over the surface of the Earth of one square cm will be only 2-4 mm (2-4 kilograms per square metre). The content of water in the Martian atmosphere will be less than 1/1000 of this quantity, i.e., less than a layer 2×10^{-4}-4×10^{-4} cm thick.

Such is the unusual dryness of the Martian air which by far exceeds anything that can be encountered in the terrestrial deserts. But the absolute humidity in saturation rapidly diminishes with a drop in temperature (approximately 1000-fold at a drop of 65°C); consequently, at the temperature of —70°C, which is observed on Mars in winter, even this negligible quantity of vapours is apt to condense into the finest observed clouds.

With an uneven distribution of vapours this process of condensation occurs even more simply. We must take into consideration that atmospheric circulation is limited, as a rule, to a definite hemisphere, i.e., the air circulates separately in each hemisphere. It is well known that there are absolutely no water reservoirs with an open surface or even small water channels on Mars. This absence of free water on the planet compels the assumption that during the melting of snow or hoar-frost, to be exact, all the vapours go directly into the atmosphere and are later recondensed. Thus, if we disregard the nearly permanent polar snows, which occupy a very small area, we may conclude that the total quantity of water on Mars is scarcely several times the amount contained in its atmosphere. The water-vapour content obtained above yields a value corresponding to 2.88×10^8 tons of water for the entire Martian atmosphere.

This is approximately from 1/1,000,000 to 1/10,000,000 the amount of water contained in the living organisms on the Earth alone. Under these conditions there can be no question of even a thin cover of snow on Mars. The observed white cover, which forms in winter, must simply consist of hoar-frost deposited on the surface of the planet and rapidly disappearing even with a small rise in temperature.

The seasonal changes on Mars are as follows. A very rare cloud of fog, probably consisting of fine crystals of ice floating in the atmosphere, gathers over the polar cap at the end of winter or in the beginning of spring. The cloud is unstable and dissipates during spring. In spring a dark border several hundred kilometres wide, in all probability resulting from the thaw, surrounds the polar cap. The darkening spreads from the respective polar cap to the equator at a rate of 45 kilometres per day. The wave of darkening crosses the equator and continues to spread in the same direction in the opposite hemisphere reaching approximately latitude 40° by the beginning of summer. According to Vocouleur this picture of changes has been established quite authentically. The entire process of the propagation of darkening from latitude 60° North to latitude 40°-South, i.e., within the latitudes of 100° for both hemispheres, is, thus, connected with the apparent movement of the Sun on Mars' firmament from the equator (beginning of spring) to the circle of the tropic (beginning of summer). When the Sun, after turning back, re-crosses the equator into the other hemisphere this wave of darkening begins to move in the opposite direction and the phenomenon symmetrically recurs in time.

It is perfectly clear that such changes cannot be the result of simple atmospheric circulation, which is limited to each

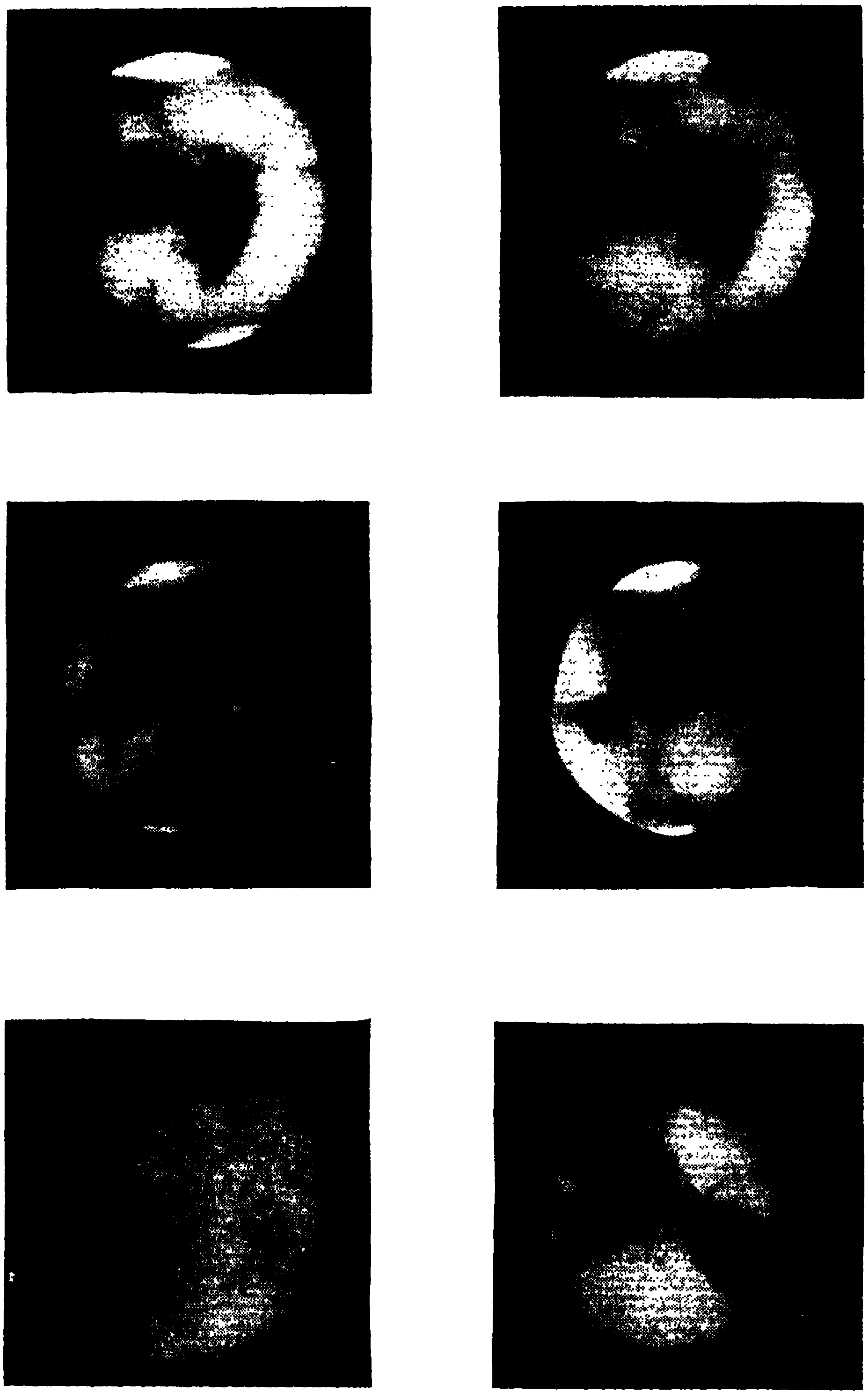

Fig. 44. Seasonal changes on Mars

hemisphere alone; to an even lesser extent can they result from the spread of some sort of moisture over the surface of the planet. Vocouleur is inclined to explain this phenomenon by atmospheric diffusion. He describes still another phenomenon, which is analogous to the darkening and which spreads over the same period of time and in the same order, but at half that rate—about 20 kilometres per day. The nature of these phenomena is as yet unknown. It should be noted, however, that N. Barabashev, who has had enormous experience in investigating Mars, makes no mention of this type of seasonal changes.

From what we know of the physical conditions on Mars today the climate of this planet can be compared only with that of imaginary Alpine plateaux on the Earth at an altitude of about 18-20 kilometres if we lower their temperature by approximately 30-40°C, greatly reduce the content of water vapours and fully or almost fully remove the oxygen from their atmospheres. Mars presents a polar, arid Alpine desert with a negligible atmospheric pressure, without or nearly without oxygen. There is no water in the form of reservoirs or streams with an open water surface of the planet. This is acknowledged by all investigators without exception since it is based on absolutely incontestable data. The amount of water in the atmosphere per one square centimetre of surface does not exceed a few hundredths of a gram. Can we suppose that with the extreme lack of surface and atmospheric water on Mars there can be much more subsoil water as is the case in the terrestrial deserts? There are, apparently, no reasons for such a conclusion since the subsoil waters on the Earth are the same surface waters which have soaked into the ground to a certain waterproof horizon.

If we compare Mars with the Earth as regards the abundance of water we shall get the following correlation. By distributing the water of the oceans uniformly around the entire surface of the Earth we get a layer several kilometres thick, while the entire similarly distributed water reserve on Mars will form a layer only a few tenths of a millimetre thick.

* * *

We shall now make some general comments as to whether life could possibly have formed and can exist on Mars by analogy with the Earth. On the Earth, despite the constant coming of seeds and germs from the regions abounding in life and despite the adaptation of new vital forms the dependence of life on the conditions of existence has been clearly manifest over millions of years. The greatest multiformity of life is in the tropics, where the temperature and, chiefly, the humidity are higher than anywhere else on the Earth. Life grows poorer and more elementary in forms the closer it comes to the poles and the higher it rises above the surface of the Earth. In the terrestrial climate orchards, forests and cultivated fields are situated at foot-hills; higher, to an altitude of 2-2.5 kilometres, there are only conifers which disappear where there is low humidity (for example, the southern and drier slope of the foot-hills of the Trans-Ilian Ala-Tau is absolutely devoid of arboreous vegetation, which, however, densely covers the northern, more humid slopes at the same altitude); still higher are Alpine meadows covered only with grasses, while higher still there are boulder-stones with thin grass. This is followed by eternal snows which, apparently, run throughout the thickness of the troposphere where the moisture is transferred and clouds form.

If the mountains on the Earth rose much higher than the troposphere, i.e., beyond the atmosphere, abounding in water vapours, at a sufficient altitude they would be deprived of the eternal snows and would retain only a dry rocky desert greatly heated in the daytime and similarly cooled at night. The temperature of the air would always keep extremely low, even in the daytime it would be much lower than the temperature of the soil. It has already been said that such an imaginary desert at an altitude of 18-20 kilometres but with a temperature a few dozen degrees lower than that on the Earth and fully or nearly fully devoid of oxygen would very closely resemble the surface of Mars as it appears according to present-day data. What life could exist on the

Earth on such an Alpine plateau? Can living organisms have a metabolism under these conditions? It would be absurd after passing the region of eternal snows and entering the arid and frozen desert to expect again grass, trees or any higher forms of vegetation, in general, which have long since disappeared at the much lower altitude. It is clear that even on the Earth, where life has existed, modified and adapted itself to the environment for many millions of years, only the most primitive of its forms could exist under these conditions.

The question as to whether life can exist on Mars can also be approached from another angle. In order for life to exist it must, certainly, first, originate on the given planet. On the basis of the physical and biological science of today the theory of panspermia—the transfer of organic germs from one planet to another—can be considered completely discredited. N. Kholodny has very vividly shown that multiform organic life could not possibly have sprung from the micro-organisms brought to the Earth from another planet according to the hypothesis of panspermia. Hence, if life in some way or other exists on Mars it must have originated on the same planet. However, under the conditions existing on Mars today the possibility of origination of life appears quite doubtful.

As a matter of fact the protein molecule consisting of four principal elements—hydrogen, carbon, nitrogen and oxygen—as well as phosphorus, sulphur and certain other elements is the basis of life. The unification of these elements and the building of a protein molecule require not only their existence on the given celestial body, but also possibilities for their free migration, opportunities for meeting which enable them to enter into various combinations. In a perfectly dry desert this is absolutely impossible. It requires some aqueous medium which contains different inorganic compounds in solution. This is why reservoirs are necessary for the origination of life. These reservoirs may be of different size, but they must ensure an active metabolism, for example through streams with sufficiently large surfaces. Life on Mars could, therefore, have originated only under conditions absolutely different from those prevailing today, i.e., a denser atmosphere, existence of open reservoirs and a higher temperature than that of today.

If should be noted that an increase in humidity and in the total quantity of water alone is by far insufficient for the formation of open reservoirs. On Mars, where the temperature is on the average 30-40°C lower than on the Earth these reservoirs would simply be frozen and never melting basins of ice, like the eternal snow and ice on the high mountains of the Earth. It has been repeatedly suggested that a drop of only 9-10°C in the mean temperature of the Earth would suffice to cause a new glacial period with a big part of the Earth again covered by a heavy coat of ice. There are no ice-spaces on Mars only because there is no water and nothing to freeze. The negligible amount of water vapour in the atmosphere of this planet forms hoar-frost, settles as such and then evaporates again owing to the fact that saturation of the atmosphere with water vapour corresponds to a very low temperature there.

The origin of life on Mars would have been enormously facilitated if the planet had a higher temperature and a much greater reserve of water. In this case, however, we would have to assume that Mars has evolved in the direction of sharp drying and cooling. There has been no such process on the Earth, as we can suppose, and there are no reasons to believe that it is taking place on Mars.

* * *

We shall now consider the question of whether there is any direct proof of the existence of organic life on Mars. Organic life on a planet manifests itself primarily in the existence of a biosphere. V. Vernadsky was the first to call the attention to the fact that life on the Earth manifests itself on a cosmic scale occupying the space from a depth of 3 kilometres to an altitude of about 10 kilometres in relation to the Earth's surface. The shell in which the vital processes occur he named the biosphere. According to V. Vernadsky, all of the outer layers of the Earth's crust have been changed by life 99 per cent as regards their weight.

The modern terrestrial atmosphere has also been created in considerable measure by living organisms, which take an active part in the migration and accumulation of many elements—C, O, N, Ca, K, Si, P, S, Fe, Mg, Mn, Cu, Zn, Na, J, etc. The organisms secrete into the atmosphere various gases, for example, O_2, CO_2, N_2, NH_3, CH_4, H_2, etc. In part, bacteria destroy organic substances liberating H_2O, CO_2 N_2, H_2S, NH_3, H_2, CH_4, etc. The tension of the biochemical energy of the living organisms is enormous.

L. Berg cites the following example: decomposition of kaolin into its component parts with the isolation of free alumina and silica in a laboratory can be effected at a temperature of at least 1,000°C, while living organisms, Diatomea, do the same at the ordinary temperature. In the inorganic crust of the Earth water and carbon dioxide never break up into their component parts; this is possible only in magma at very high temperatures. But living organisms do it on a tremendous scale at the ordinary temperature.

The bacteria play an exceptional role. It is well known that even alumosilicates—unusually stable compounds, constituting, according to Vernadsky, more than half the Earth's crust and easily resisting sulphuric acid, are decomposed by special bacteria. Silicate bacteria destroy even granite and prepare the soil for the growth of plants.

At the same time living organisms have the ability to multiply extremely rapidly under favourable conditions. Thus, for example, the choleraic vibrio can produce in a single day 6.4×10^{28} individuals representing 61-62 generations. Even the simplest seaweeds, Diatomea, can produce five generations a day. Under conditions of unimpeded reproduction the living organisms could fill the globe in an extremely short time: the choleraic vibrios in 1.25 days, the

Diatomea in 16.8 days, the green plankton approximately in 168-183 days, the flies in 366 days and the chickens in 15-18 years.

V. Vernadsky estimates the total weight of living substance in the terrestrial biosphere at approximately 10^{14}-10^{15} tons, which constitutes 10^{-4} of the weight of the Earth's crust. The quantity of free oxygen in the atmosphere and hydrosphere is comparable with the weight of living substance and constitutes approximately 1.5×10^{15} tons.

Free oxygen is a product of the green vegetable world. This is well known and needs no proof. It is interesting to note that, unlike the other gases, free oxygen in the terrestrial atmosphere is in a state of dynamic equilibrium: it is constantly spent on the processes of oxidation and is constantly renewed by the activity of the green plants. Had it not been for the plants, oxygen could have completely disappeared from the atmosphere in a few years. L. Berg observes that the amount of free oxygen that passes annually through living substance corresponds approximately to its total quantity contained in the air, namely, 10^{15} tons. Besides the green plants oxygen is also produced as a result of decomposition of water by the ultra-violet radiation of the Sun and by radio-active substances. These processes, however, are absolutely insignificant. We must not think that the process of oxygen isolation is conditioned mainly by the higher chlorophyll plants. The plankton in the oceans is of tremendous importance in this respect; plankton occupies an area of millions of square kilometres at an average thickness of 100 metres. A certain part of the atmospheric oxygen is created in this film where green plants are abundantly represented.

The great cosmic role of the living substance, which constitutes the biosphere, is conditioned by the processes of exchange with the environment which is accompanied by the most powerful chemical reactions, as well as rapid reproduction, i.e., increase in the quantity of living matter, and, lastly, by the long existence of the biosphere corresponding to at least one thousand million years. During this time the living substance has remade the surface layers of the Earth and created the soil and all sorts of local accumulations of ores and deposits, as well as a new atmosphere of secondary origin, mainly of a nitrogen-oxygen composition. It should be noted that free oxygen was not only created, but is preserved by life without which it could not have persisted because of its extraordinary intense chemical activity. Free oxygen is, thus, a characteristic of the biosphere which exists at the given moment on the planet under consideration.

The question of atmospheric nitrogen is more complicated. This gas is relatively inert and can, therefore, apparently, persist in the atmosphere for a very long time. At the same time atmospheric nitrogen can only be of secondary origin and must, therefore, have formed after the final formation of the Earth. This clearly follows from the fact that only negligible traces of inert gases of different atomic weights have persisted in the terrestrial atmosphere though they all belong to elements extensively widespread in nature. Academician V. Vernadsky believes that all of the atmospheric nitrogen is of a biogenic nature. If this were true nitrogen in the atmosphere could serve as a sign that organic life existed on the given planet in the past at least in the form of bacteria—nitrifiers, capable of binding atmospheric nitrogen, and denitrifiers, capable of liberating this gas from inorganic compounds—nitrates and nitrites.

However, modern data of geochemistry definitely indicate that, unlike oxygen, free molecular nitrogen can be liberated as a result of tectonic processes from great depths where the temperature is high enough to break up the nitrogen compounds without the aid of living organisms. On the other hand, the considerations that living organisms participate in the creation of molecular nitrogen have not as yet any quantitative grounds which renders the appraisal of the real significance of organisms in the formation of the terrestrial atmosphere extremely difficult.

On the basis of the foregoing we may, thus, conclude that free oxygen in the atmosphere of a planet is the only incontestable criterion in the question of the existence of a biosphere on it. The existence of molecular nitrogen cannot serve as such a criterion. No free oxygen has been discovered on Mars. We must, therefore, conclude that there is no biosphere on Mars either. Organic life has not manifested itself on this planet on a cosmic scale as it has on the Earth.

* * *

If we take it that there is no biosphere on Mars, maybe organic life still manifests itself there in separate, at least very small, areas? As has already been pointed out it is most generally accepted that the Martian maria with their seasonal changes in reflective ability and colouring are areas covered by vegetation. G. Tikhov even supposes that this vegetation may belong to the higher deciduous and coniferous forms which have adjusted themselves to the severe conditions of this planet and, in particular, have lost the ability intensely to reflect solar rays in the nearest infrared part of the spectrum. These considerations are backed up by the results of the investigations of the Section of Astrobotany of the Kazakh Academy of Sciences conducted, it is true, only with respect to green vegetation under different terrestrial conditions. G. Tikhov writes about the Martian vegetation surmised by him: "What kind of vegetation can we think of on Mars? In the first place this must be an undersized vegetation pressing closer to the ground. It must be essentially grasses and creeping bushes of a green-blue colour.... The Martian plants may remotely resemble our Alpine and polar junipers, cranberry, cowberry, moss, lichens and other northern and Alpine plants."

We have already mentioned that the existence of some forms of vegetation on Mars is asserted or at least considered quite probable by many investigators in the U.S.S.R. and abroad.

We shall now examine the actual evidence in favour of this assertion. The most favourite method extensively used with reference to Mars is the study of the distribution of the reflective ability of its various details in different spectral rays by means of light-filters or, in rare cases, the spectrograph.

It is well known that green vegetation is usually noted for its small maximum of light-reflection in the region of the spectrum about 560 mμ (chlorophyll maximum), as well as its sharply defined infra-red excess. Green foliage photographed through a light-filter, which filters only infra-red rays, looks as if it were covered by snow and is sharply defined against the perfectly dark background of the sky. These peculiarities are most clearly manifest in spring on fresh green vegetation and are somewhat smoothed down in autumn as is well seen on the spectrophotometric curves obtained by Y. Krinov under various conditions.

What are the spectral peculiarities of the dark spots on Mars, its maria or oases—the only regions of the planet where the existence of vegetation can be assumed? The Martian maria in no way resemble terrestrial vegetation spectro-photometrically. The green maximum cannot essentially be established there. Its presence would lead to an incredibly small contrast in the green rays between the light and dark regions on Mars which would be at variance with the observations. The infra-red excess is also absent and the Martian maria, therefore, appear most contrasting in these rays as compared with the deserts.

The extensive investigations of the Section of Astrobotany of the Kazakh Academy of Sciences show, however, that the aforesaid spectro-photometric peculiarities are not necessary even for green plants. During the severe seasons when the growth dies down their spectral reflective ability considerably changes and approximates the reflective ability of minerals. The lower plants, as, for example, lichens, have only a minimum of these properties. On the other hand, certain inorganic substances also have an infra-red excess. It follows that the spectro-photometric method is not efficient. Its use does not make it possible to judge whether the Martian maria are areas occupied by vegetation or not.

The seasonal changes in the colouring of the maria and their greenish or even bluish shade are essentially the best argument in favour of the existence of vegetation on Mars. Here, however, we enter a very unreliable sphere of purely subjective appraisals and run into the fact that many observers using one and the same telescope report absolutely different results. We could cite many examples of these contradictions.

After describing many striking cases of changes in the contours of the Martian maria N. Barabashev comes to the following final conclusions in his summary article on the changes in the visibility and form of the dark spots on Mars:

a) In most of the cases the colour of the maria changes towards red as the Sun approaches the horizon.

b) The overwhelming majority of the maria is reddish compared with the white screen. The observed blue shades are due to purely subjective sensations which arise as a result of the contrast between the colour of the maria and the even redder deserts.

c) In some cases the dark regions are moistened sections of deserts.

d) The relative darkening and change in the shades do not contradict the hypothesis of vegetation in corresponding regions of the planet.

It is, evidently, impossible to say anything definite about the existence of vegetation on Mars on the basis of the colour changes except that we do not know any other reasons for these changes. Incidentally, N. Barabashev cites in the same article an example of a mineral—Tikhvin bauxite—which turns noticeably blue when merely moistened. We must note that the quantitative spectro-photometric observations enable us at least to take into consideration and isolate the distorting influence of the Martian atmosphere, while the purely qualitative appraisals of the colouring are, certainly, absolutely worthless in this case.

We shall now use other and more reliable criteria in solving the problem of what the Martian maria are and whether they have any vegetation that determines their observed properties. It has been firmly established that the temperature of the soil of the Martian maria is 10-15°C higher than that of the deserts. This corresponds to the darker appearance of the maria. It goes without saying that a darker inorganic substance absorbs a greater measure of solar rays which fall on it and must be heated correspondingly to a higher temperature. The entire process consists only in absorption and heating. We are warranted in the assertion that the mechanism of heating is the same for the Martian maria as it is for the deserts, i.e., it comes down to a mere absorption of solar rays with an immediate return radiation. A little calculating will prove this contention.

Let us assume that the reflective abilities of the desert and the sea A_1 and A_2 are 0.30 and 0.15 respectively. Then according to Boltzmann's well-known law the temperature of the sea T_2 can be obtained from that of the desert temperature T_1 on the basis of the expression

$$T_1 = T_2\left(\frac{1-A_1}{1-A_2}\right)^{\frac{1}{4}}$$

and turns out to be 15°C higher, as it is really observed. The result would be entirely different if the properties of the seas were determined by vegetation. Vegetation, whatever it may be, behaves in a way quite different from that of a simple mineral. The solar energy it absorbs is spent on complex photochemical processes and these processes are extremely intensive. Owing to this the radiation of the surface of the soil taken up by vegetation can never be so intensive as the radiation of the much lighter surface of a mineral substance under the same conditions of irradiation. A dark oasis midst a hot sandy desert, or grass growing along the sides of a dusty road heated by the Sun are always much cooler. The very essence of a living plant consists in the fact that it spends the energy received from the Sun on different vital processes and not at all on simple heating. The dark Martian spots are undoubtedly governed by the usual laws of heating and radiation established by physics for inorganic bodies without noticeable selective peculiarities, and their observed properties cannot, therefore, be conditioned by the existence of vegetation.

In the small foregoing calculation we used Boltzmann's formula. It does not mean, however, that we ascribe the properties of an absolutely black body to the surface of Mars. We operate essentially only with a radial flux —the only magnitude that can be directly observed. The calculation shows that with a greater absorption of energy the heat output of the heated surface grows in the same proportion whether it be a Martian mare or a desert. The situation would be entirely different if the observed properties of the maria were determined by vegetation.

The law of reflection of light from their surface may serve as another criterion for judging the nature of the Martian maria. It has been firmly established that the reflection of light from the surface of Mars quite accurately corresponds to Lambert's Law. In other words, Mars reflects light like an even dead surface. By V. Sharonov's proposal this is expressed in the assertion that the factor of evenness for Mars is close to unity. An entirely even sphere fully illumined by the Sun and located at a considerable distance from the observer will appear to him brighter in the centre and much darker on the edges of the disk. Suffice it to look at Mars to see that this law is applicable to it, and not only to its deserts but also to its "maria." As the maria approach the edge of the disk (due to Mars' daily rotation) their brightness considerably diminishes.

Thus, Mars' deserts and maria reflect light according to the same law. The factor of evenness of the Martian maria is also very near unity. It is well known that the reflection of light by a lustreless opaque substance is determined by the properties of its surface in the thickness of the same order as the length of lightwave. The smallest details, for example, small cracks, etc., on the surface can completely change the nature of the reflection of light.

Contrariwise, any type of vegetation, according to N. Orlova's definition, is characterized by a very small and even negative factor of evenness and in this respect presents a striking contrast with the ordinary dead surfaces. This, apparently, also pertains to the characteristic properties of any vegetation which receives its nutrition from the surrounding aerial environment and therefore strives to develop the greatest possible surface contact with this environment. The total surface of the foliage of any tree or bush through which carbon dioxide is assimilated is many thousand times as large as the even surface of the area occupied by this tree. It is, apparently, this striving of the vegetable organism to utilize the environment as fully as possible that serves as the cause of the sharp difference of its factor of evenness from the ordinary dead surfaces composed of inorganic substance. Thus, the nature of light reflection from the Martian maria, recently established by the studies of Soviet scientists, is completely at variance with the assertion that they present areas covered by vegetation.

Another criterion that can be used for determining the nature of the dark spots on Mars consists in comparing them with deserts by the degree of polarization. Such measurements were taken, first, by Lyot at the Meudon Observatory and lately by his pupil Dollfus.

Polarization is very closely connected with the state of the reflecting surface. Apparently incontestable observations show that the polarization of the maria is absolutely the same as that of the light areas—the deserts. A change in polarization, and a very temporary one at that, is observed only in the narrow dark border that surrounds the melting polar snow. The remaining area occupied by the dark spots in no way differs from the obviously lifeless deserts at any time of the year. In addition, Dollfus observes that our vegetable areas sharply differ in polarization from the dark Martian spots. All the very authentic and objective criteria, thus, belie the assumption that the reflective properties of the Martian maria are conditioned by the existence of some sort of vegetation.

But what are the Martian maria really? Why do they differ in their greener colour from the deserts? Why are they subject to seasonal and epochal changes? Why have they not been buried by sand and dust, but have persisted for, probably, hundreds of years?

Persuaded there can be no vegetation on Mars, MacLaughlin recently proposed his volcanic hypothesis to explain the main peculiarities of Mars' surface. He believes there is a good deal of volcanic activity on Mars even today and that the volcanoes, located chiefly in the regions of the tectonic breaks and cracks, from time to time eject clouds of ash which is deposited on the surface of the planet. He deems it possible to assert that the distribution of the principal contours of the Martian maria follows in the direction of the winds in its atmosphere and the maria must, therefore, be formed by the deposits of the volcanic ashes carried by the winds. Resumed activity of the same volcanoes results in deposits of fresh ashes and preserves the Martian maria and their details with the various inevitable changes. According to him the green colour of the maria is the unavoidable result of the interaction between the chemical composition of the volcanic ashes and the Martian atmosphere. The basalt and andesite ashes contain a high percentage of ferro-magnesial silicates. On the Earth, where there is an abundance of free oxygen, the wind erosion of these silicates results in the formation of ferric oxides and hydro-oxides distinguished for their red, yellow and brown colours. Contrariwise, on the Mars, where there is no oxygen, the carbon dioxide with a small amount of moisture acting on the same minerals changes them to secondary minerals, known as peaches and epidotes. Under terrestrial conditions these minerals are formed at sufficient depths inaccessible to free oxygen. On Mars these minerals form on the very surface. They are notable for their green colour. Thus, the regions on Mars occupied by the deposits of volcanic ashes, i.e., precisely the areas of the maria, are inevitably coloured green. The seasonal changes in the maria

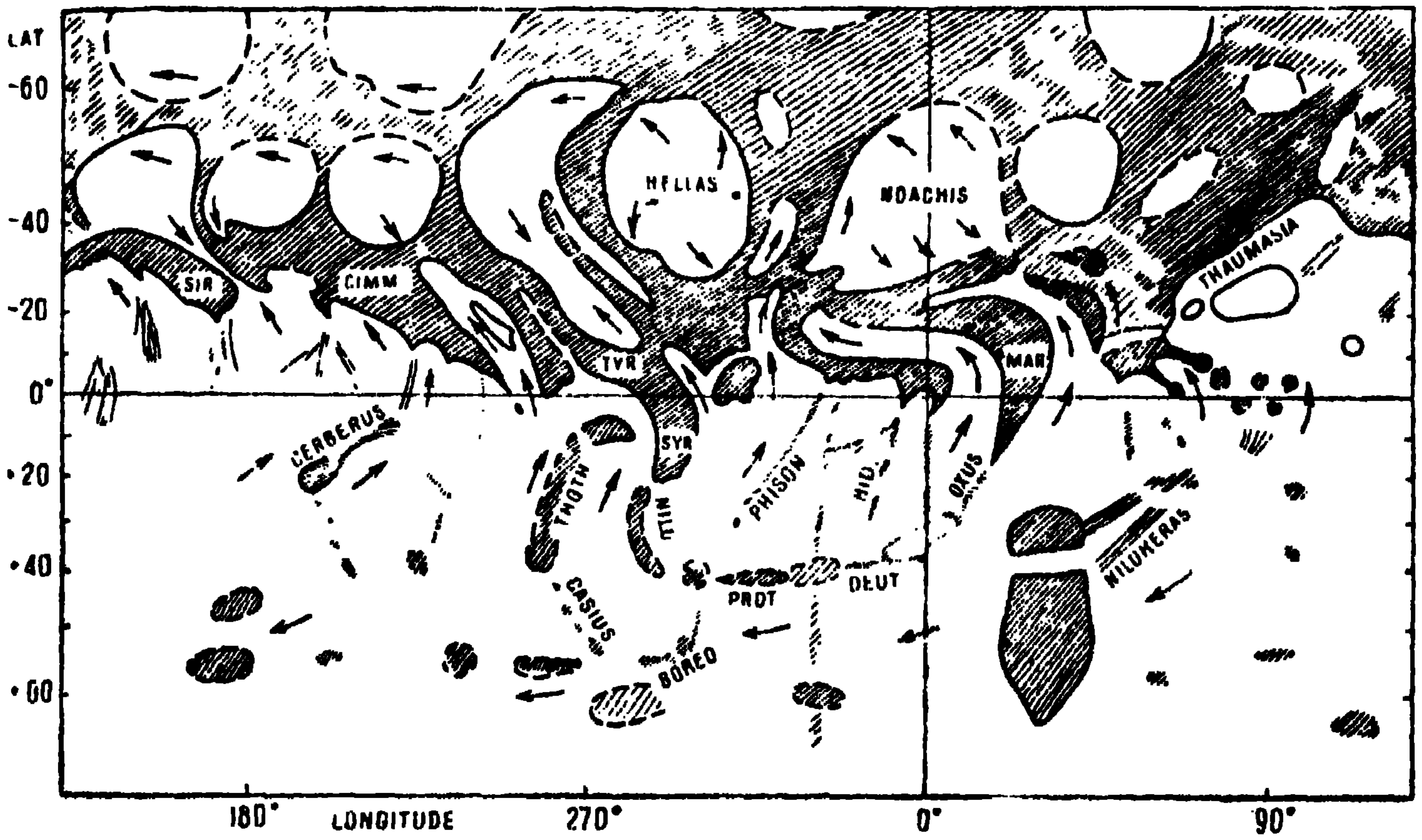

Fig. 45. Contours of the maria on Mars and the direction of the winds (after MacLaughlin)

are conditioned by the changes in the direction of the winds, humidity and temperature. The systematic direction of the canals is also connected with the ejection of volcanic ashes in a definite direction.

Thus, the volcanic theory corresponds much closer to the data of observations, i.e., the absence of oxygen on Mars, the fact of the considerable heating of the maria compared with the yellow deserts, the total likeness between these maria and deserts, as far as the law of light-reflection is concerned, the nature of polarization, etc. This theory assumes, however, that there is extensive volcanic activity on Mars today and that the structural peculiarities of the maria correspond to the direction of the prevailing winds. The latter is quite probable, but cannot be considered definitely established. The direction of the winds on Mars cannot be studied by the movements of the clouds in its atmosphere because of the rarity of cloud formations. It is clear, however, that the general atmospheric circulation on this planet must not differ from that on the Earth, that there must also be a zone of trade winds there which are deflected from their direction by the rotation of the planet. Local corrections can be made in this general circulation of air currents on the basis of a detailed study of the distribution of the isotherms. The existence of anticyclones, which upset the general regularity of the atmospheric circulation and lend different peculiarities to the configuration of the maria, has been established in certain regions of the Martian surface.

The temperature of Mars' clouds and numerous points on its surface will undoubtedly be taken during its nearest favourable oppositions in order to ascertain the thermal conditions at different altitudes of the free atmosphere. The values of the daily and seasonal lag in the maximum of temperature will also be determined; this will help in ascertaining the heat conductivity of its soil and the amplitude of temperature fluctuations. A great deal must still be done in studying the clouds and general atmospheric circulation on Mars; particular efforts must be made to find sufficiently persuasive data on the intensity of volcanic activity on the planet. All this together with detailed investigations in the appearance and structure of the details on Mars' surface will make it possible with much greater accuracy to determine the nature of the Martian maria and the reasons for their systematic and seasonal changes.

Despite the insufficient data we can already conclude that there are no direct indications as to the existence of life on Mars. The dark spots on this planet are not maria, as was formerly believed, nor oases covered with vegetation as many still think today. But even if there is no biosphere on Mars, if life on the planet does not manifest itself on a cosmic scale and has not been discovered by any observations from the Earth we cannot as yet be sure that no living organisms, even though the most primitive, could have persisted since the time when the conditions on Mars may have been more favourable to life than today. It would be overbold to assert that there must be no life whatsoever on Mars. At the same time there are no reasons for illusions as to more favourable conditions on Mars in the past. Judging by the extraordinary small mass of this planet we can assume that already at the time of its formation it could retain light gases in much smaller quantities than, for example, the Earth and for this reason there were never any vast water areas on Mars. The processes of water cycle, during which the reservoirs may have gradually acquired many dissolved chemical elements necessary for the formation of the extraordinary complex living substance, could never have occurred there.

On the Earth the process of geological preparation, which made it possible for the primary forms of life to come into being, continued during the first several thousand million years of its existence. As far as we can judge, life on the Earth has existed for no more than one thousand million years while its most primitive fossil forms are not older than 300-400 million years. Thus, the higher forms of life have been developing on the continents, on the solid soil of the Earth, only during approximately one-tenth of the time our planet has existed. The conditions for the origin and development of life on Mars have always been by far more severe than on the Earth. There can be no doubt that no higher forms of plant or animal life can exist on this planet. It is quite possible, however, that life in its lowest forms does exist there, though it does not manifest itself on a cosmic scale.

* * *

Maybe the conditions for the existence of life are more favourable on Venus than they are on Mars? In size and mass this planet resembles the Earth more than any other planet and at the same time it is located somewhat closer to the Sun and, thus, gets approximately twice as much light and heat per unit of surface. It may be assumed from the very outset that there must be organic life there, which, as we should think, always comes into being wherever favourable physical conditions obtain as a result of the development of inorganic matter. It is our task, however, without confining ourselves to general statements to discover facts which definitely speak in favour of the existence of life on this planet. It should be noted from the very beginning, however, that the conditions for observing Venus from the Earth are worse than those for observing Mars. The reason is clear. Venus is an interior planet. It is closer to the Sun than the Earth and can, therefore, be observed only as an evening or morning luminary at an angular distance from the Sun of not higher than 40°, presenting all phases —from a full disk to an extremely narrow crescent and even to complete disappearance (analogous to the new Moon).

When the disk of Venus is fully illuminated by the Sun it is farthest from the Earth at the opposite point of its orbit at the enormous distance of 1.7 astronomical units or 250 million kilometres. This is approximately 5 times the distance between the Earth and Mars during favourable opposition. On the other hand, when Venus comes closest to the Earth it is turned to it with its unilluminated side. This is why only a small part of its surface can be simultaneously observed even under sufficiently favourable conditions when Venus is at a relatively large angular distance from the Sun. During its conjunctions with the Sun, when the longitudes of both luminaries are equalized, Venus is sometimes higher and sometimes lower than the Sun and only rarely passes exactly across the Sun projecting itself on the solar disk. It is curious to note that on approaching the Sun the horns of Venus' crescent become ever more elongated and finally close in a continuous ring which can be easily photographed. This is explained by twilight phenomena in the planet's atmosphere. The existence of an atmosphere on Venus was established by M. Lomonosov when he observed the planet passing across the disk of the Sun in 1761.

The main aim in observing this passing was to determine the solar parallax and the scale of the solar system by the method proposed by Halley. This phenomenon could be observed on a vast territory—from Petersburg to Eastern Siberia—and the Petersburg Academy of Sciences organized these observations under Lomonosov's general supervision. Of all the numerous observers, however, Lomonosov was the only one to discover the existence of an atmosphere on Venus. When the planet's disk approached the Sun very closely Lomonosov discerned a luminous rim around it and rightly concluded there was a sufficiently dense atmosphere around Venus noticeably scattering the solar rays and producing the phenomenon of twilight. It was only later that these observations were fully confirmed and supplemented by corresponding micro- and photometric measurements.

It can be quite easily seen with modern observing technique that the surface of Venus, unilluminated by the direct rays of the Sun, emits a weak light resembling the earth-shine of the Moon. This phenomenon is quite analogous to the luminescence of the nocturnal sky on the Earth which emanates from the high layers of the terrestrial atmosphere (the ionosphere). But the luminescence of Venus' own atmosphere is more intense than that of the terrestrial atmosphere. This is, very probably, due to the fact that Venus is much closer to the Sun. Interesting spectrograms showing the nature of the luminescence of Venus' own atmosphere were obtained at the Crimean Astrophysical Observatory in 1953. With the aid of a quartz spectrograph mounted on the 125-cm reflector of the observatory N. Kozirev happened to discover a row of nitrogen emission bands, of which the most intensive ones—3914 and 4278 Å—belonging to ionized nitrogen are characteristic of the spectrum of the northern lights. Thus, the luminescence of Venus' nocturnal sky is, apparently, analogous to our northern lights and, therefore, has much greater energy of radiation than the ordinary night sky of the terrestrial atmosphere. It is interesting to note that while there is nitrogen and some other gases whose existence can be surmised by the as yet undeciphered bands in the spectrum Venus is, apparently, completely devoid of oxygen. In the spectrum of the nocturnal terrestrial sky with a much lesser energy of excitation oxygen is represented by intensive emission lines. The considerable absorption in the violet part of the spectrum of Venus' unilluminated surface and the two clear edgings of molecular bands at 4372 and 4120 Å show, according to N. Kozirev, that there is some atomic molecule in Venus' atmosphere which, possibly, plays the same part as water vapours do on the Earth. No water vapours proper, however, have been found. On the basis of the discovered emission bands N. Kozirev calculated that the brightness of the nocturnal sky on Venus must be approximately 50 times as great as that of the nocturnal terrestrial sky and may be only one-fifth that during the full Moon.

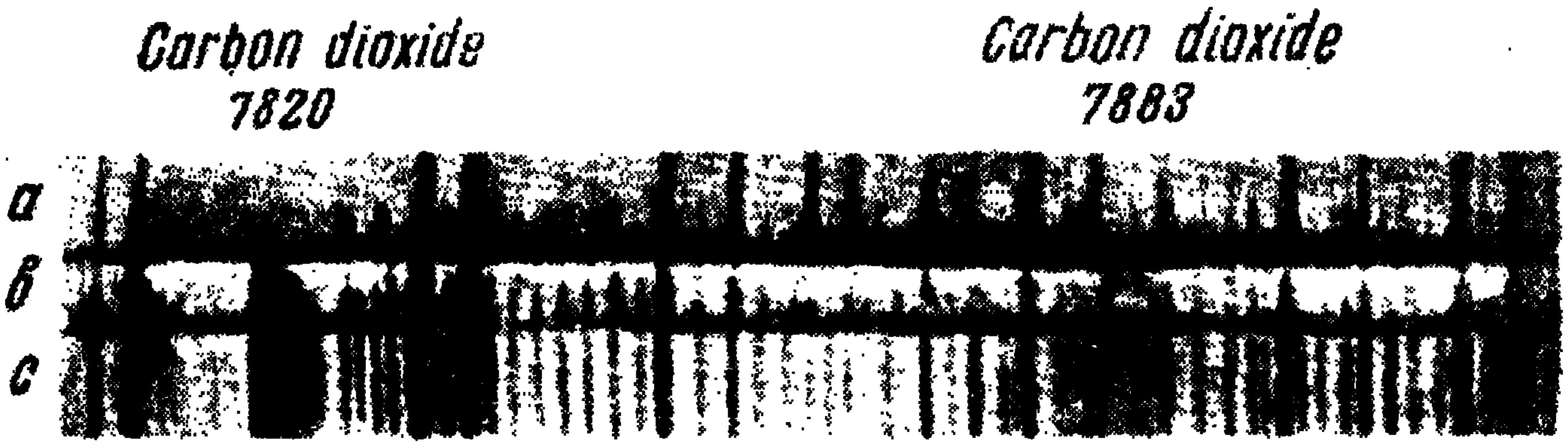

Fig. 46. Infra-red spectra of the Sun and Venus. a) the Sun, b) Venus, c) Extended spectrum of Venus;

It is much easier to study Venus' spectrum presented by its brightly illuminated surface which must show the line of absorption of the solar rays penetrating to the very cloud layer of this planet and reflected from it back into cosmic space. The visible region shows the same absorption lines which are peculiar to the solar spectrum. In 1932, with the aid of a large 250-cm reflector of Mount Wilson Observatory, Adams and Dunham found three intensive bands in the infra-red region of Venus' spectrum; these bands are absent on the Sun and belong to carbon doixide. The theoretical calculations and direct experiments performed by Adel and Slipher enabled them to determine the quantity of carbon dioxide in Venus' atmosphere by the intensity of these bands. For comparison they used light which passed through a layer of carbon dioxide 45 metres thick under a pressure of 47 atmospheres. The spectrum thus obtained fully corresponded to the discovered absorption bands on Venus, but was much less intensive.

These studies have shown that the quantity of carbon dioxide over the visible surface of Venus corresponds to an equivalent layer of this gas approximately three kilometres thick under standard atmospheric pressure and at standard temperature. It may be pointed out for comparison that on the Earth this layer of carbon dioxide is only 8.4 metres thick. It has been, thus, ascertained that the atmosphere of Venus, which, it would seem, should be very much like the Earth, contains a tremendous quantity of carbon dioxide. At the same time not the least traces of water vapour or free oxygen have been found in the atmosphere of this planet. It should be noted, however, that the quantitative spectroscopic analysis of the contents of these substances is not very accurate. Generally speaking, various elements do not show themselves in the absorption spectrum with the same ease. It is well known, for instance, that a perfectly negligible, almost imperceptible admixture of sodium, which depends on the mere presence of the observer near the laboratory apparatus, is enough to show clear lines of this element in the absorption spectrum. Ionized calcium is similarly discovered with almost similar ease in the spectrum of the Sun though there is much less of it there than hydrogen. A modern spectrograph can discover oxygen on Venus, as well as on Mars, even if they contain 1,000 times as little of it as there is in the terrestrial atmosphere. In the usual solar spectrum water vapours produce numerous absorption lines and bands. On Venus these bands (which could be easily separated from the bands of a terrestrial origin on the basis of the Doppler effect) are absolutely invisible.

It should be noted, however, that all the observations of Venus bear only on the layer of atmosphere above the clouds, usually completely hiding the surface and not on the planet's surface itself. As a matter of fact, one is very much disappointed when observing Venus through a telescope because there are hardly any details on its disk. Only at times is it possible to discern some dim spots mainly in the central region of the terminator which usually retain their position for a long time. Even photographs with infra-red rays fail to reveal anything new on the planet save what has already been found by visual observation. This shows that the layer of clouds covering the planet is entirely opaque and, therefore, either consists of relatively large particles of dust or is very heavy.

On the other hand, the photographs made in ultra-violet rays often reveal light clouds which form quite noticeable protuberances on Venus, especially on the terminator itself. These light clouds are, in all probability, formations similar to our cirrous clouds and are located at a high altitude in Venus' atmosphere. When they are absent the atmosphere of Venus is enveloped in a heavy yellowish fog which barely reflects the ultra-violet rays of the solar spectrum.

Since we can never observe the surface of Venus it is impossible to determine the period of its rotation on its axis. On the basis of the very slow changes in the position of the hazy dark spots scientists at one time concluded that Venus rotates extremely slowly and, in all probability, like Mercury always shows the same side to the Sun.

A. Belopolsky made a detailed study of the possible period of Venus' rotation by the spectroscopic method using the Doppler effect in an attempt to establish the shift along the line of sight in the absorption lines of the light reflected from the two opposite edges of the disk. He discovered no noticeable shift, however, and, hence, concluded that the day on Venus is equivalent to at least several weeks on our

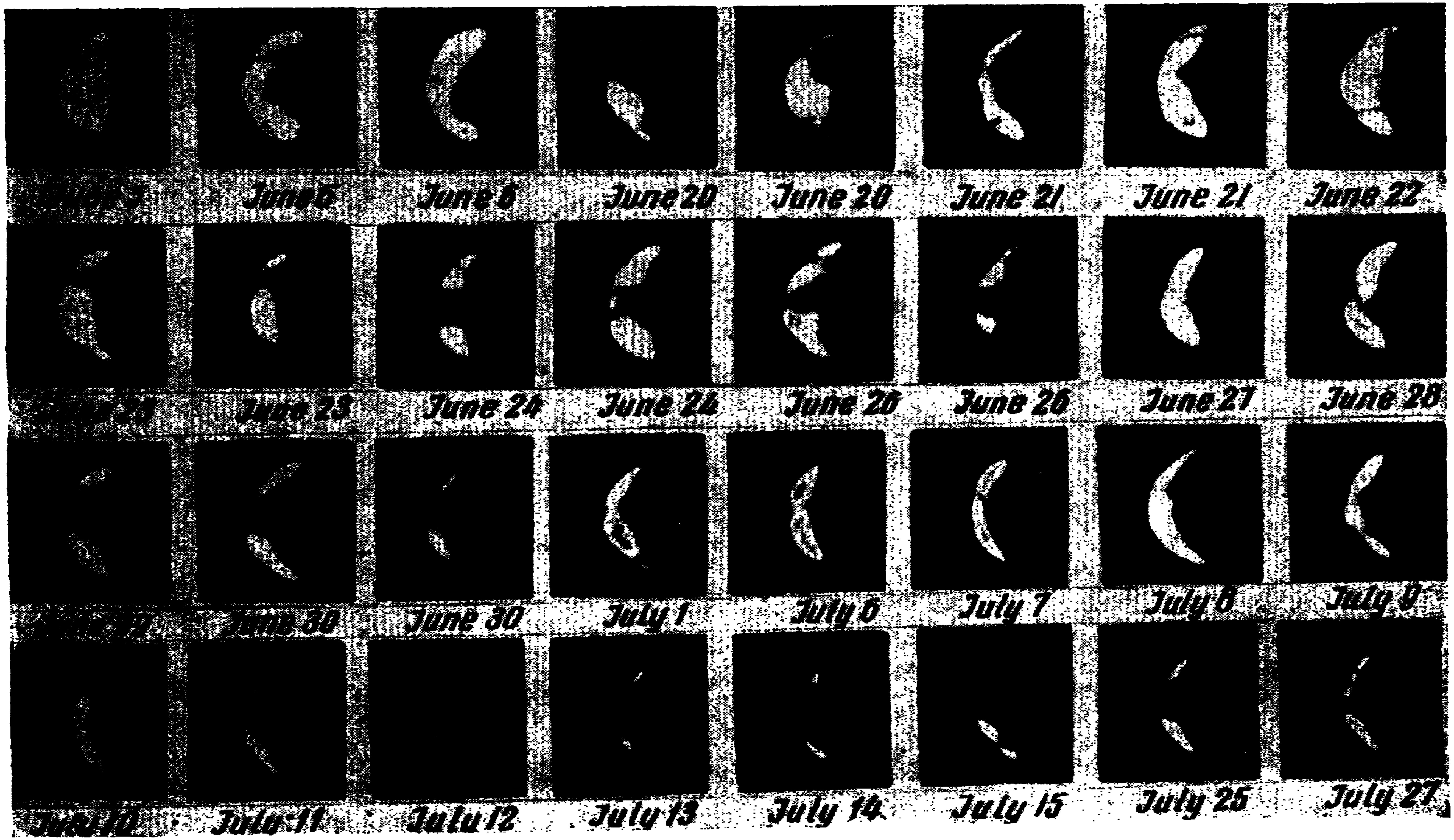

Fig. 47. Photographs of the crescents of Venus with cloud formations

planet. This is all that can be said about the period of its rotation at the present time.

Some indirect indication as to the length of the day on Venus can be found in the temperature difference between its diurnal and nocturnal surface. If Venus always faced the Sun with the same side, there would be a very great difference in temperature between the side facing the Sun and the opposite side—at least 150-200°C. But direct radiometric measurements have shown that the temperature of the diurnal and nocturnal sides of Venus is nearly the same and is about —30°C (Pettit and Nicholson). By the structure of the infra-red bands of carbon dioxide Adel and Hertzberg found that the temperature of the illuminated part of Venus corresponds to +30°C, which characterizes the temperature of the medium of the absorbing layer rather than simply the intensity of the radiation of the planet as a heated body. It is obvious that Venus cannot face the Sun with one side but the period of its rotation must be, according to A. Belopolsky's inferences, at least several weeks.

To consider the question of the possibility of life on Venus requires knowledge of the chemical composition of its atmosphere, as well as the state and temperature of its surface. It is clear that the atmosphere of Venus has nitrogen, large quantities of carbon dioxide and some other gases, which vigorously absorb light in the blue rays; no oxygen or water vapours have been discovered, however. A certain dustiness in Venus' atmosphere manifests itself in the fact that its light scattering sharply differs from purely gaseous scattering. This has been very definitely established by numerous studies of N. Barabashev and his associates at the Kharkov Astronomical Observatory, V. Sobolev and E. Shenberg. A gaseous medium with an admixture of a certain amount of aerosols scatters the light much more forward, i. e., in the direction of the passing ray, than back, and this asymmetry increases the greater the size of the scattering particles. In a purely gaseous medium light is scattered according to the simple law of Rayleigh, i.e., in proportion to

$1+\cos^2\vartheta$ if we take ϑ as the angle between the incident and scattered rays. According to V. Sobolev, this indicatrix for the atmosphere of Venus is even more elongated than the similar indicatrix for the terrestrial atmosphere. This testifies to the existence of relatively large scattering particles in Venus' atmosphere, i.e., to a considerable dustiness in the atmosphere of Venus even above its cloud layer. N. Barabashev has come to the same conclusion.

How can these facts be interpreted? No doubt there can be very little water vapours above the cloud layer of Venus, if they exist at all, but this is not as yet a decisive argument against the existence of water on this planet. At a low temperature of the high atmospheric layers the pressure of water vapours can be so insignificant that modern observing technique may prove insufficiently accurate to discover it. But what is the nature of this planet's cloud layer? Wildt has suggested that a combination of carbon dioxide and water vapours was possible on Venus with its insignificant water content; during this process a poison gas formaldehyde (CH_2O) is formed and free oxygen liberated. This suggestion is at variance with facts because no formaldehyde absorption bands located in the ultra-violet part of the spectrum beginning with 3600 Å, nor any oxygen absorption bands, are found in the spectrum of Venus. D. Menzel and F. Whipple believed it possible that the cloud layer on Venus consists of water vapours just the same; this also corresponds to the former studies of Lyot who found that the curve of polarization of Venus' light is very similar to the polarization of a cloud composed of small droplets of water. But the absorption of light in such clouds cannot be discovered by the nature of the spectral lines.

It is very hard to say how extensive the cloud layer over the surface of Venus can be. This yellowish layer is, most probably, not very heavy and is, possibly, even translucent, weakly revealing the surface underlying it. Two facts speak in favour of this assumption. Firstly, according to Minnaert's studies based on the observations of E. Shenberg and N. Barabashev, the layer of clouds on Venus has different structures in the morning, at noon and in the evening, if we only assume that the planet has a noticeable rate of rotation in the same direction as the Earth. The distribution of brightness on Venus' disk, noted by the aforesaid observers, can be explained only in the light of this assumption. If these changes in the cloud layer occur systematically the layer cannot be extensive. Secondly, the cloud layer of Venus shows some signs of mirror reflection, which can be attributed only to the surface underlying it. As it has been found by N. Barabashev, the maximum of brightness in the red and yellow rays corresponds to the sections of the planet for which the angle of incidence and the angle of reflection are almost exactly equal with the incident and reflected rays lying on different sides of the normal in accordance with the law of mirror reflection.

Of itself the diffuse cloud layer could not have produced this effect. Let us assume, however, that Venus is covered by a vast aqueous surface similar to the terrestrial oceans. In this case the solar rays, reflecting mirror-like from this surface, must inevitably produce a bright patch of light which should be very well seen from the Earth as a bright point. The cloud layer partly transparent to the solar rays and located above will considerably weaken this patch which the terrestrial observer will see as simply a brighter diffuse spot. We may also recall that, according to Menzel and Whipple, great quantities of carbon dioxide on Venus are incompatible with the existence of continents on the planet because in the presence of water, which acts on mineral rocks, there must inevitably be a fixation of carbonates, i.e., formation of solid carbonic compounds consuming the gaseous carbon dioxide from the atmosphere.

A similar process binding gaseous carbon dioxide occurred on a large scale on the Earth with the result that the mineral carbon deposits in the form of coal, peat, oil, different carbonates, limestone, etc., by far exceed the content of carbon in the atmosphere. On the Earth this process occurred mainly because of the activity of plants over many millions of years, but it can also take place in some measure in the presence of water which moistens the hard surface of the continents, especially at a sufficiently high temperature.

If the whole amount of mineral carbon buried in the Earth were again released into the atmosphere in the form of carbon dioxide the Earth would contain quite as much atmospheric carbon dioxide as Venus. We must, thus, evidently, assume that for some reason or other this epochal process of carbon fixation did not occur on Venus. This fact seems to speak against the existence of vegetable and, consequently, animal life on Venus. The reason for this anomaly may, according to Menzel and Whipple, be that Venus is completely covered by an ocean—by a continuous water mantle. In the light of this assumption we can understand both the absence of free oxygen, which can form only as a result of the epochal manifestation of photosynthesis, and the persistence of tremendous quantities of gaseous carbon dioxide on Venus.

We must, apparently, conclude that the observed data speak rather against the existence of life on Venus, at least in its higher forms.

Chapter VIII

LIFE IN THE UNIVERSE

In its constant development matter pursues various courses and may acquire different forms of motion. Life, as one of these forms, results each time the requisite conditions for it are on hand anywhere in the Universe.

However, life must not necessarily arise on all celestial bodies. On the contrary, neither the surface of the stars with their monstrously high temperature, nor the cold clouds of gas and dust matter can serve as a place for the origin and development of life. These processes have occurred but on the surface of planets and then only if, as and when there were the necessary chemical compounds and the aforesaid physical conditions during their formation and subsequent evolution.

Can such conditions obtain in the Universe and if so how often?

Firstly, for organic life to be possible the planet must receive from its star a certain constant amount of radiation. The orbit of the planet must be close to circular, and the star must, therefore, not be a double or multiple star around which there can be no regular and simple orbits. In addition, the star must emit a certain constant radiation, it must not be a variable star with a big amplitude, or an explosive novae, etc.

The radius of the planet's orbit must also keep within narrow limits. Only then will the necessary temperature on the surface of the planet be guaranteed. In our solar system only Venus, the Earth and Mars of all planets satisfy this requirement. The other planets cannot be inhabited. It is particularly important that the mass of the planet be neither too large nor, on the contrary, too small. If, for instance, the mass of the planet constitutes 1/100 of the mass of the Sun its own temperature is too high and it differs but very little from a star.

With a mass 1/1000 that of the Sun the temperature of the planet is already entirely negligible, but the planet is still capable of retaining around itself the primary gases—hydrogen, ammonia and methane in the proportions characteristic of the distribution of the elements in the cosmos. Such a planet will be surrounded by an enormous atmospheric mantle with different products of condensation and its hard core will not be accessible to irradiation by the Sun. Jupiter, Saturn and the other superior planets of our solar system are in this state.

Besides, Jupiter receives 1/30 the heat received by the Earth and the temperature on it corresponds to approximately —140°C. But even if this planet were close enough to the Sun life could not originate on it anyway because of its atmosphere abounding in hydrogen.

On the other hand, a planet with too small a mass cannot retain an atmosphere or have any water in a liquid state. The Moon, on which not the least trace of water and wind activity, of any atmosphere and, hence, any life can be seen, is in this state.

It should be noted that the planet and, consequently, the star around which it revolves, must be old enough for the necessary migration of the ashy elements to have taken place, for the complex organic substances, especially proteins, to have formed and for the long natural process of selection of coacervates to have occurred. The Earth has already existed for nearly 4,000 million years and during the first thousands of millions of years of its existence, when the conditions on its surface as regards heating and water differed only slightly from those of today, there was, apparently, no life on it.

Thus, it requires a planet to have existed a very long time for life to originate and gradually develop as a result of the preliminary preparation of the environment in the form of aqueous solutions with many elements dispersed in them and a combination of a number of necessary conditions. Near the young stars, on the young planets, which are forming now or which formed only tens or hundreds of millions of years ago there can be no life as yet.

Let us approximately estimate quantitatively the probability of the existence of life on a hypothetical planet in the vicinity of a star chosen at random. We shall start with the assumption that every star in the Universe is, as a rule, the centre of a planetary system. Since we cannot be absolutely sure of it the result obtained will, apparently, be only the possible maximum of the probability sought for.

As has been pointed out above, the first essential condition for the possibility of life is the approximately circular form of the planet's orbit. Only with such an orbit will the planet as a whole receive about an equal amount of light and heat from its star. It follows that none of the double or multiple systems of stars can come under our consideration since the planetary orbits around the double and multiple stars are extraordinarily complex. Thus, only single stars can have inhabited planets near them.

But even near such stars the planets must have approximately circular orbits. Thus, with a relatively small eccentricity of only 1/4, the illumination of the planet per unit of its surface changes during one revolution around its star three times. Taking into consideration the fact that about 80 per cent of the stars form part of the double or multiple systems and that by far not all the orbits can be circular we can approximately estimate the probability of the form of orbit fit for life to originate as about 0.1. All the massive, actinic and, consequently, relatively young stars must, undoubtedly, be excluded from the number of the remaining single stars.

For its origin and subsequent development life requires

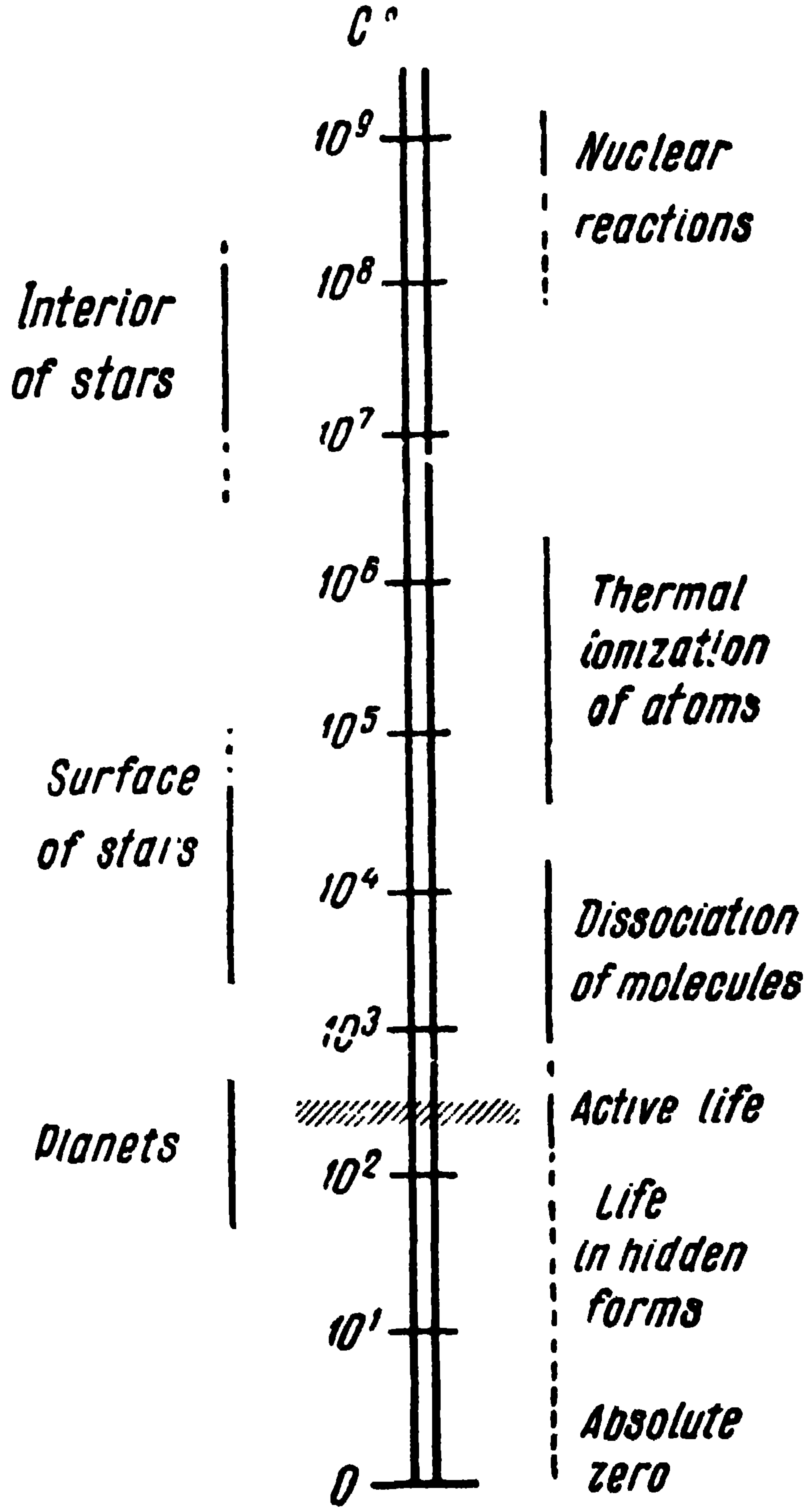

Fig. 48. Scale of cosmic temperatures

very long periods measured in hundreds and thousands of millions of years. During the entire respective period the planet must receive an approximately constant amount of energy from its Sun. Meanwhile, all sufficiently massive stars quite rapidly lose their mass due to corpuscular radiation and, thus, weaken the gravitational forces which bind the planetary systems. The change in mass is paralleled by a diminution of the luminescence of such stars. Because of this the illumination of a planet by a star changes in proportion to the sixth power of the star's mass.

With the epochal diminution of the star's mass by only 10 per cent the average illumination of the planet diminishes nearly two-fold. Only near the quite established and sufficiently old stars like our Sun can the planets be sure of light and heat without any noticeable changes for many millions of years. But even near such stars the planets must go through a very long period of preliminary preparation which ensures the requisite and sufficiently full enrichment of the very superficial medium with the most diverse elements through the age-old process of substance circulation. By analogy life could not have originated at once on the recently formed Earth because there had been no suitable medium for it.

Considering the fact that among the stars now being formed many may have quite normal dimensions, but only gradually acquire stability, and considering the fact, furthermore, that all the massive stars must be excluded, we may take it that no more than 10 per cent of all the single stars are sufficiently stable and, at the same time, old enough. Consequently, the probability of this factor is also small.

It is, furthermore, essential to remember that the very mechanism of planet formation requires sufficiently big intervals between the planetary orbits if only the planets have normal masses fit for the development of life. As is well seen on the example of our solar system only few (one or two) of the large number of planets can get into the interval of distances favourable enough for the maintenance of life. The other planets will inevitably be either too close to, or, on the contrary, too far from their central luminary. Thus, of the total number of planets, whose upper limit it is quite hard to establish, possibly no more than 10 per cent will get into the necessary favourable interval of distances. Consequently, the probability of this factor—planetary distances—will also be approximately the same.

It has already been pointed out that in order to be a carrier of life a planet must have an optimum mass, neither too large nor too small. This is, as can well be imagined, one of the most rigid, if not the most rigid, requirements. As a matter of fact, planets of any mass—from stellar to asteroid—are likely to form depending on the state of the initial gas and dust medium surrounding the forming star.

All sufficiently large masses, from 10^{29} g on, retain about them all the elements in their normal abundance peculiar to the cosmos and are unfit for life at least for this reason. All small masses, lower than 10^{25}g, cannot retain any gas mantles at a temperature normal for life. The required mass of a planet must, therefore, be within a very narrow interval of all possible planetary masses which corresponds to the well advanced process of elimination of the light gases, essentially the loss of the primary atmospheres and, at the same time, every possibility of retaining their secondary atmospheres. In particular, the mass of the planet must contain enough hydrogen to make possible the formation of sufficiently large masses of water which may ensure the cycle of water in nature. At the same time the requisite mass of the planet, apparently, also ensures the necessary chemical composition of its air mantle.

What is the probability that a planet will receive the necessary mass during its formation or, in other words, what part of all possible planets has the necessary mass? This is very hard to say. It may be supposed that this part will barely exceed one per cent of all possible planets.

It may, therefore, be assumed that the probability of life in the vicinity of any star taken at random in our Galaxy will be approximately 1/100,000 or even 1/1,000,000. Consequently, only one star out of a million taken at random can possibly have a planet with life on it at some particular stage of development.